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# Three-dimensional hydrostratigraphy of the Sprague, Nebraska area: results from helicopter electromagnetic (HEM) mapping for the Eastern Nebraska Water Resources Assessment (ENWRA)

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# **Eastern Nebraska Water Resources Assessment**

## **Three-dimensional hydrostratigraphy of the Sprague, Nebraska Area: Results from Helicopter Electromagnetic (HEM) mapping in the Eastern Nebraska Water Resources Assessment (ENWRA) 2009**

**Dana P. Divine and Jesse T. Korus**

**Bulletin 4 (New Series)**

**Conservation and Survey Division  
School of Natural Resources  
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*Photo on cover: Helicopter and geophysical equipment fly over farm buildings in the Sprague study area. All photographs by Dana Divine.*

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# INTRODUCTION

Groundwater resources under much of eastern Nebraska are contained within or beneath Quaternary glacial deposits. The heterogeneity and complexity of these deposits have hindered efforts to characterize them in detail. Test-hole drilling alone is not effective for mapping these units over large regions, but in certain settings, borehole data can be integrated with geophysical methods to map hydrostratigraphic units at high resolution and in three-dimensions. This study integrates test hole drilling and Helicopter Electromagnetic (HEM) surveys to characterize the hydrostratigraphy of an area around Sprague in southeast Nebraska.

Helicopter Electromagnetic (HEM) surveys were flown in 2007 at three pilot study sites in eastern Nebraska as part of the ongoing Eastern Nebraska Water Resources Assessment (ENWRA), a collaborative study between six of Nebraska's Natural Resources Districts, the Conservation and Survey Division (CSD) of the School of Natural Resources at the University of Nebraska–

Lincoln, the Nebraska Department of Natural Resources (DNR), and the United States Geological Survey (USGS). The rationale and history behind ENWRA are outlined in Divine et al. (2009). The purpose of the pilot studies was to assess the effectiveness of HEM at mapping the complex geology of Quaternary alluvial and glacial deposits. The pilot studies were conducted at three sites that together encompass the wide range of hydrogeologic settings in eastern Nebraska. The Firth site, which is located adjacent to the Sprague area in the present study, overlies a paleovalley aquifer that is mantled by thick glacial deposits. Korus et al. (2012) demonstrated that major hydrostratigraphic boundaries in the upper 50 – 80 meters (approximately 160 – 260 feet) of the subsurface could be interpreted from HEM data in this geological setting. The results of the pilot study at Firth prompted resource managers to extend the study area to the west around the town of Sprague in southeastern Lancaster County. The results of the Sprague study are presented herein.

## PHYSICAL SETTING

The study area lies within the Dissected Till Plains, a physiographic area that includes eastern Nebraska and parts of Iowa, Kansas, Minnesota, Missouri, and South Dakota (USGS, 2003). Aquifers in this part of eastern Nebraska occur primarily within unconsolidated Quaternary deposits. A brief summary of the geology of this region is given below. For a more detailed description, see Korus et al. (2012).

Upland areas are underlain by a succession of unconsolidated sediments consisting, in descending order, of

1. Late Pleistocene loess, chiefly the Peoria Loess;
2. One or more glacial tills of pre-Illinoian age, which contain or are underlain by stratified sands and silts; and
3. a succession of well-sorted to poorly-sorted sands and silts, with minor gravels;

Loess, till, and stratified sands and silts are present under all uplands in the study area, though thick sub-till sands and silts are present only in buried paleovalley fills.

The primary aquifer in southern Lancaster County is a west-northwest to east-southeast trending paleovalley fill

consisting primarily of sand and gravel. It extends nearly 70 kilometers (approximately 45 miles) from the eastern margin of the High Plains Aquifer near Dorchester, eastward to Sterling, where it merges with another paleovalley aquifer (Fig. 1). It is overlain by several tens of meters of glacial deposits containing relatively impervious, clay-rich tills that may pass laterally over short distances into highly permeable sands and gravels, which serve as local, isolated aquifers in some areas. Some of these aquifers, however, may be in hydraulic connection with the underlying paleovalley aquifer. In the study area, the paleovalley aquifer and glacial aquifer units with which it is connected constitute the Crete-Princeton-Adams Groundwater Reservoir of the Lower Platte South Natural Resources District (NRD).

Bedrock beneath the unconsolidated Quaternary deposits in the Sprague area consists of Pennsylvanian, Permian, and Cretaceous units (Fig. 2). Burchett (1986) and Burchett et al. (1972) mapped bedrock beneath most of the paleovalley in the study area as the Upper Pennsylvanian-Lower Permian Admire (Pa) and Council Grove Groups (Pcg) and the Lower Cretaceous Dakota Formation (Fig. 1). In general, Pennsylvanian and Permian rocks in eastern Nebraska are considered aquitards, although some shallow domestic wells in nearby areas withdraw water from the upper parts of these units where they are weathered and fractured. The



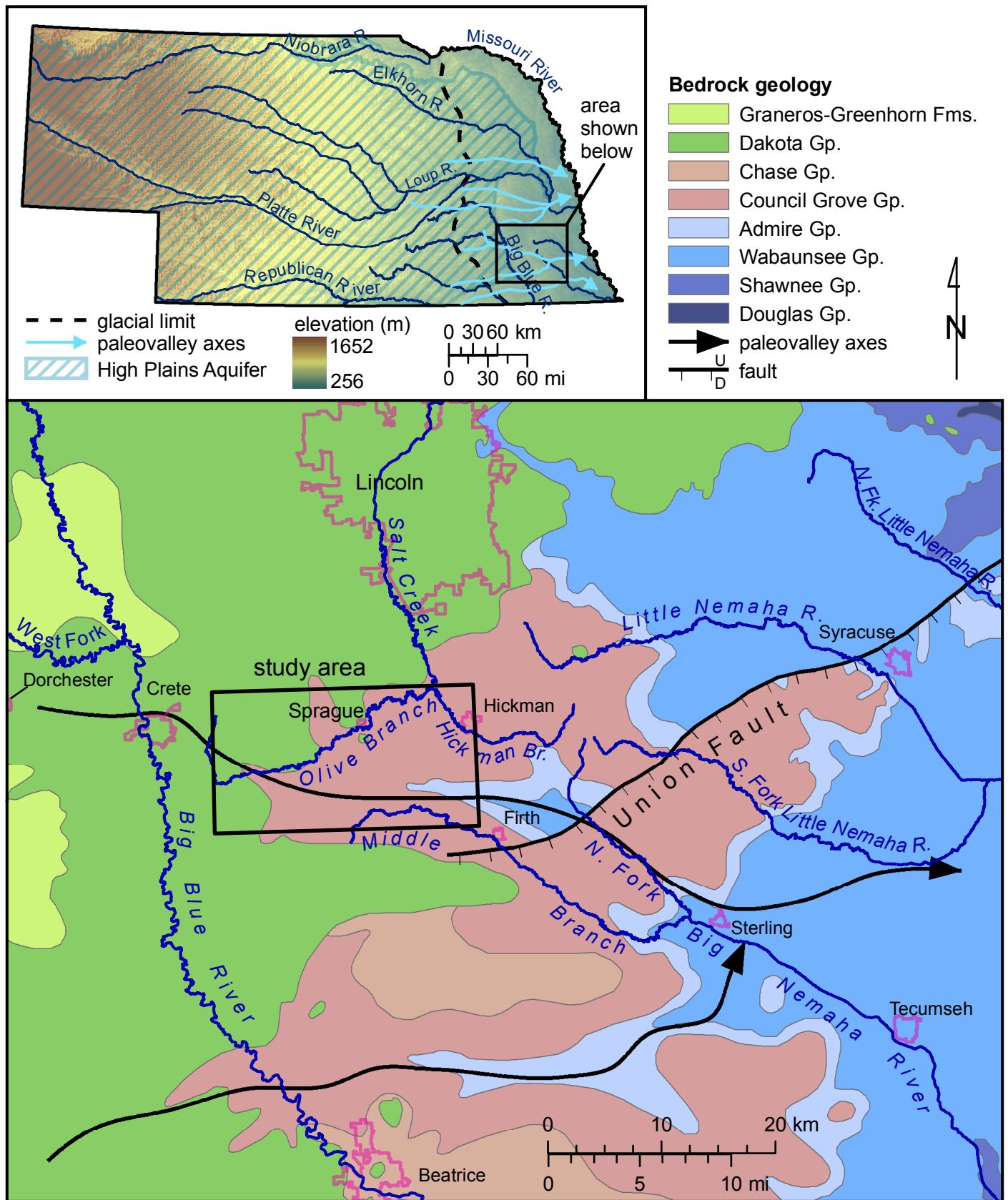


Figure 1. Map of the study area. Black box in inset map shows location of lower map. Lower map shows principal geological features in the vicinity of the study site, shown as a black outline. Bedrock geology from Burchett (1986).

Cretaceous Dakota Formation underlies Quaternary deposits on the northern and southern margins of the paleovalley where the depth of incision was shallower than in the axis of the paleovalley. The Dakota Formation thickens westward due to gentle regional dip

and is present under the axis of the paleovalley in the western part of the study area. It consists of sandstones and mudstones and is considered a secondary aquifer where Quaternary sands and gravels are thin or absent.

AGE	SYSTEM		STRATIGRAPHIC UNIT	max. th. ft (m)	SIGNIFICANCE IN TERMS OF GROUNDWATER
0.01 0.02 0.04 0.64	<b>Quaternary</b>	Holocene	DeForest Formation	15 (4.6)	<i>local alluvial-fill aquifers (minor)</i>
			Peoria Loess		
		Pleistocene	Gilman Canyon Formation	26 (8)	<i>non-aquifer materials</i>
			Loveland Loess		
			Pre-Illinoian tills with localized ribbon sands and larger sand bodies	108 (33)	<i>sands are upper aquifer and part of lower aquifer of this report; tills are aquitards</i>
2.6	<b>Neogene</b>	Pliocene	Dorchester-Sterling paleovalley fill sediments	230 (70)	<i>part of lower aquifer of this report; a primary aquifer in parts of southeastern Nebraska</i>
5.3			-----?-----		
99.6	<b>Cretaceous</b>	Upper	Dakota Formation	>50 (15)	<i>bedrock unit with minor, patchy distribution under study area; a secondary aquifer in eastern Nebraska;</i>
		Lower			
299.0	<b>Permian</b>	Lower	Council Grove Group	110 (34)	<i>bedrock units functioning mostly as aquitards under study area, but several low-capacity wells are developed in fractured limestones near bedrock surface</i>
	<b>Pennsylvanian</b>	Upper	Admire Group	82 (25)	
			Wabaunsee Group	350 (106)	

~~~~~ major disconformity      NB: maximum thicknesses (max. th.) are for Firth study area only

Figure 2. Stratigraphic chart of the study area showing age, thickness, and significance in terms of groundwater.

## GROUNDWATER ISSUES

Challenges to the management of groundwater quality and quantity exist in the Sprague area. Overdevelopment may result if groundwater withdrawals exceed the aquifer yield. Estimating the aquifer yield, however, requires detailed information regarding its extent, thickness, hydraulic conductivity, and recharge rate. These details have not been fully resolved in the study area. Furthermore, stream-aquifer connections, which affect aquifer yield and integrated management of surface and groundwater, are not accurately understood at the local scale. Groundwater quality issues involve agricultural contaminants and elevated salinity.

Elevated levels of nitrate-nitrogen have been detected in the community water supply for the Villages of Sprague and Hickman. These levels have triggered the Lower Platte South NRD to initiate additional investigation and increased management of agricultural fertilizer applications (Lower Platte South Natural Resources District, 2012). It is, however, difficult for resource managers to accurately address these issues using the existing geological framework. Details regarding aquifer thickness, extent, interconnectedness, and degree of confinement will allow managers to address both quality and quantity issues at a local level.



# MATERIALS AND METHODS

A helicopter electromagnetic (HEM) survey was conducted over the study area in April and May, 2009. Detailed specifications of this survey are contained in Smith et al. (2011) and are briefly summarized here. The survey consisted of 44 east-west traverses with approximately 280 meter spacing, five north-south tie lines with variable spacing, and one southwest-northeast tie line for a total of 1,084.2 line kilometers (~674 miles) (Fig. 3). In addition, four east-west traverses were flown through parts of the 2007 Firth HEM flight area to tie the two surveys together. Apparent resistivity values were derived from electromagnetic field measurements at five separate frequencies. Apparent resistivities were later transformed into resistivity-depth values using inversion algorithms as described in Smith et

al. (2011). Interference from power lines and other structures was monitored in the 60 hertz (Hz) signal.

Nine test holes were drilled in 2010 and 2011 as a part of this study (Fig. 3). Core was obtained from these test holes using a split spoon auger rig system. Augers were advanced until penetration was denied by the resistance of unconsolidated materials and mud rotary drilling was used at the same location to advance the test holes through the remainder of unconsolidated materials and into bedrock. Downhole geophysical logs (gamma ray, resistivity, and in some wells, caliper) were recorded for the full depth of each borehole. Cores and cuttings were described in the field or laboratory by geologists and are archived at CSD. Additional geologic data used in this report was

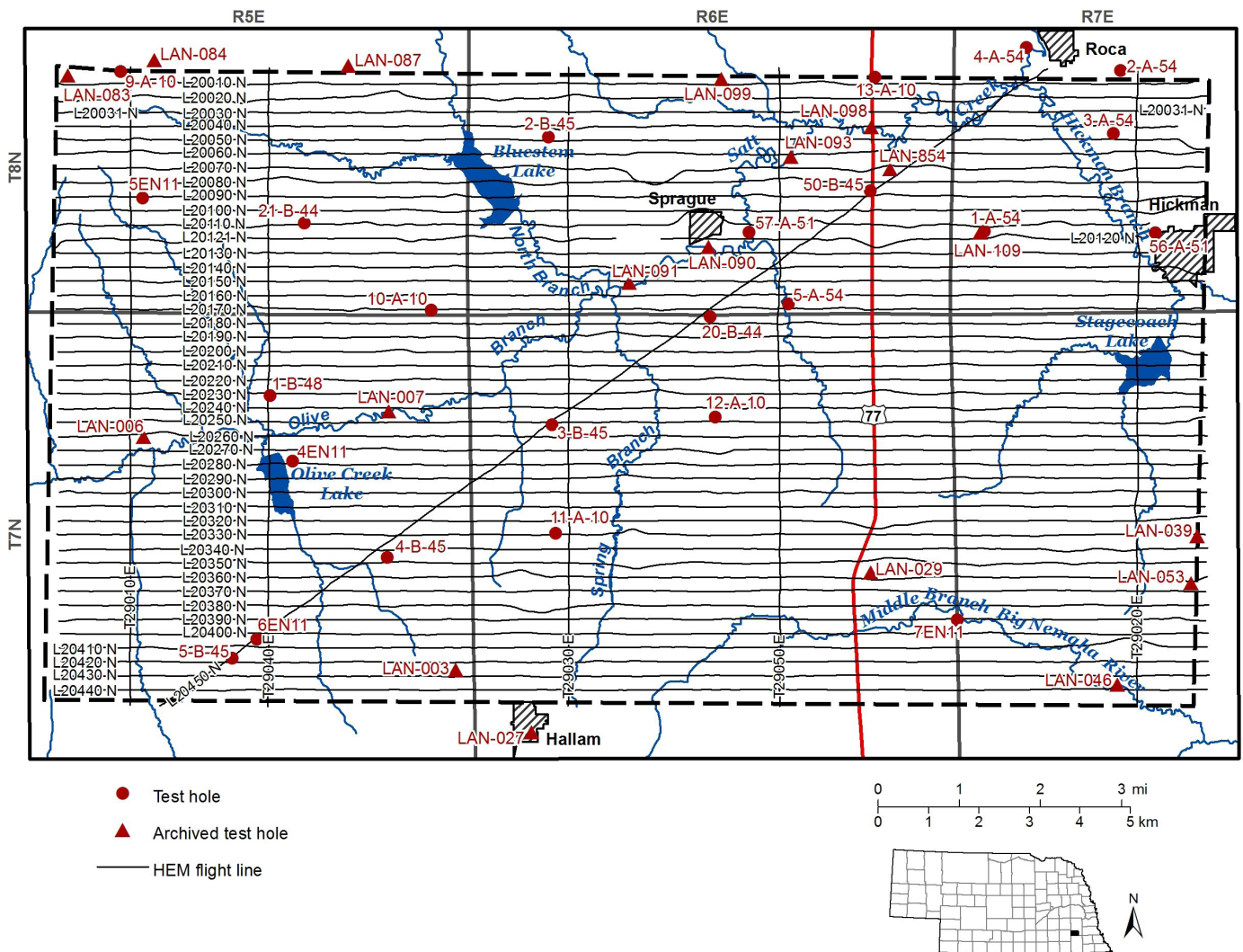


Figure 3. HEM survey area. Numbered flight lines are presented relative to the locations of test holes. Circles represent test holes that were drilled by CSD and are part of the statewide test hole database. Triangles represent test hole logs that were not drilled by CSD, but are kept in archived files at CSD.

compiled from historical CSD test holes (Burchett and Smith, 2003); driller's logs contained in the Department of Natural Resources (DNR) registered wells database (NDNR, 2009); and unpublished test hole logs archived at CSD.

Details regarding the methods used to jointly interpret the test hole data and inverted HEM profiles are provided in Korus et al. (2012). The same analytical methods were applicable to both the Sprague and Firth sites due to their proximity and similar hydrogeologic setting. The data is collected and analyzed using units of meters. The large volume of data makes wholesale conversion of the dataset to feet impractical, but for the convenience of the reader, we have used US Customary Standard Units wherever possible. In

some diagrams, the values and categories are given in unusual multiples due to conversion.

Several creeks are present in the survey area, but Olive Branch/Salt Creek is the most prominent (Fig. 3). The creek occupies one valley and is named Olive Branch upstream of the North Branch and Spring Branch tributaries and Salt Creek downstream of this three-way confluence. Hickman Branch Creek is located in the northeast corner of the study area, and the Middle Branch of the Big Nemaha River is located in the southeast corner of the survey area. Three flood-control lakes are also present in the survey area: Olive Creek Lake on a tributary to Olive Creek; Bluestem Lake on North Branch Creek; and Stagecoach Lake on a tributary to Hickman Branch Creek.



*HEM survey being conducted near the Sheldon power plant north of Hallam, Nebraska.*



# RESULTS

## Test Holes and HEM profiles

Subsurface resistivity profiles were constructed by plotting resistivity-depth values from Smith et al. (2011) along flight lines using Encom PA, a commercially available software program. Figure 4 depicts three of these profiles, annotated to emphasize hydrostratigraphic contacts and cultural interference. All of the profiles (not annotated) are included in Appendix A. The datum for each sounding point along the profile is the topographic surface derived from an USGS 10-m digital elevation model. Resistivities from 10 to 40 ohm-meters were mapped to a logarithmic color scale ranging from dark blue to pink. Borehole logs within 100 – 300 m of the flight line were superimposed on the resistivity-depth

profile. Anomalous HEM resistivities resulting from power lines and other infrastructure were recognized by high 60 Hz signals.

Comparison of borehole data to HEM resistivities show that, in general, thick high resistivity units indicate materials composing major aquifers whereas thick low resistivity units indicate materials composing major aquitards (Fig. 4). Thin or deeply buried sand bodies may not be recognizable in the HEM profiles. For example, most of the thick sand unit in the lower half of test hole 21-B-44 is not imaged by the HEM (Fig. 4). Thin sand and gravel units, such as those in the lower

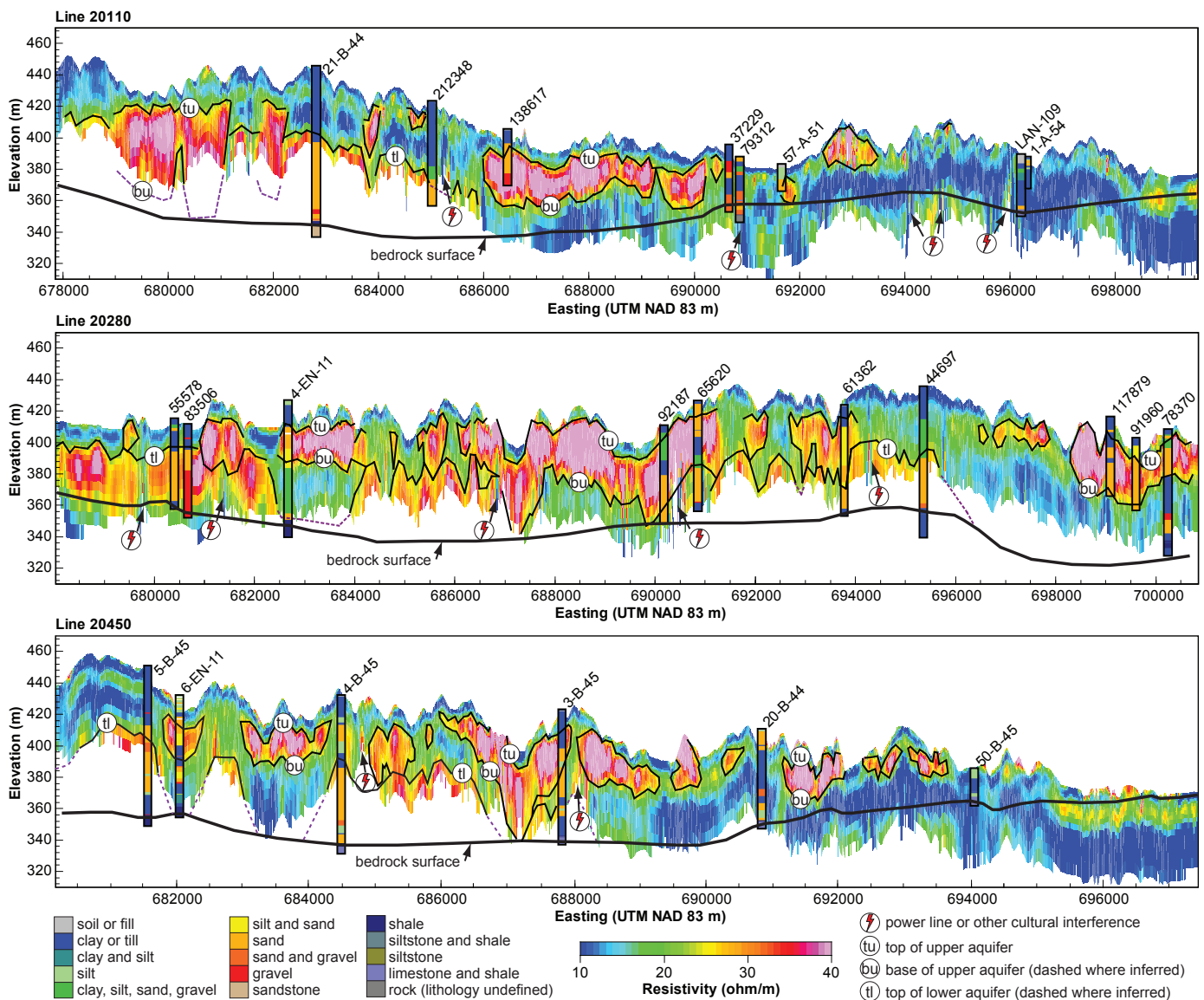


Figure 4. Inverted HEM data from three flight lines with test hole lithologies superimposed. Thick black lines represent interpreted bedrock surface. Thin black lines represent interpreted boundaries of the upper and lower aquifer material.

part of test hole 20-B-44, do not appear in the HEM. On the other hand, some high resistivity bodies in the HEM do not correspond to sand in the test holes, such as in the logs of registered wells 92187 and 65620 in line 20280. We attribute this lack of correlation to either poor lithologic and location control of registered well logs or lithologic variability between the location of the borehole and the line of the HEM profile. We highlight these inconsistencies because it is important to recognize that there is error associated with the datasets and our

interpretation of them. Nonetheless, the lithology and resistivity match relatively well in most locations and our interpretation of them is likely a reasonable estimate of actual conditions. HEM resistivity in the study area does not appear to be controlled in any systematic fashion by factors such as degree of water saturation and groundwater chemistry (Korus et al., 2012). The boundaries of major hydrostratigraphic units, therefore, can be mapped by correlating contrasts in the HEM resistivities.

## Groundwater Levels

A combined water table/potentiometric surface map (Fig. 5) was prepared for the study area using data from 202 wells located within one mile of the flight area. Data from 26 of these wells were collected in the spring of 2009 when the HEM flights occurred. The other measurements were taken by drillers during well

installations from 1991 to 2011. Water levels measured during the irrigation season (June through September) were discarded. Stream surface elevations read from a topographic map were used to constrain the water table elevation in valleys.

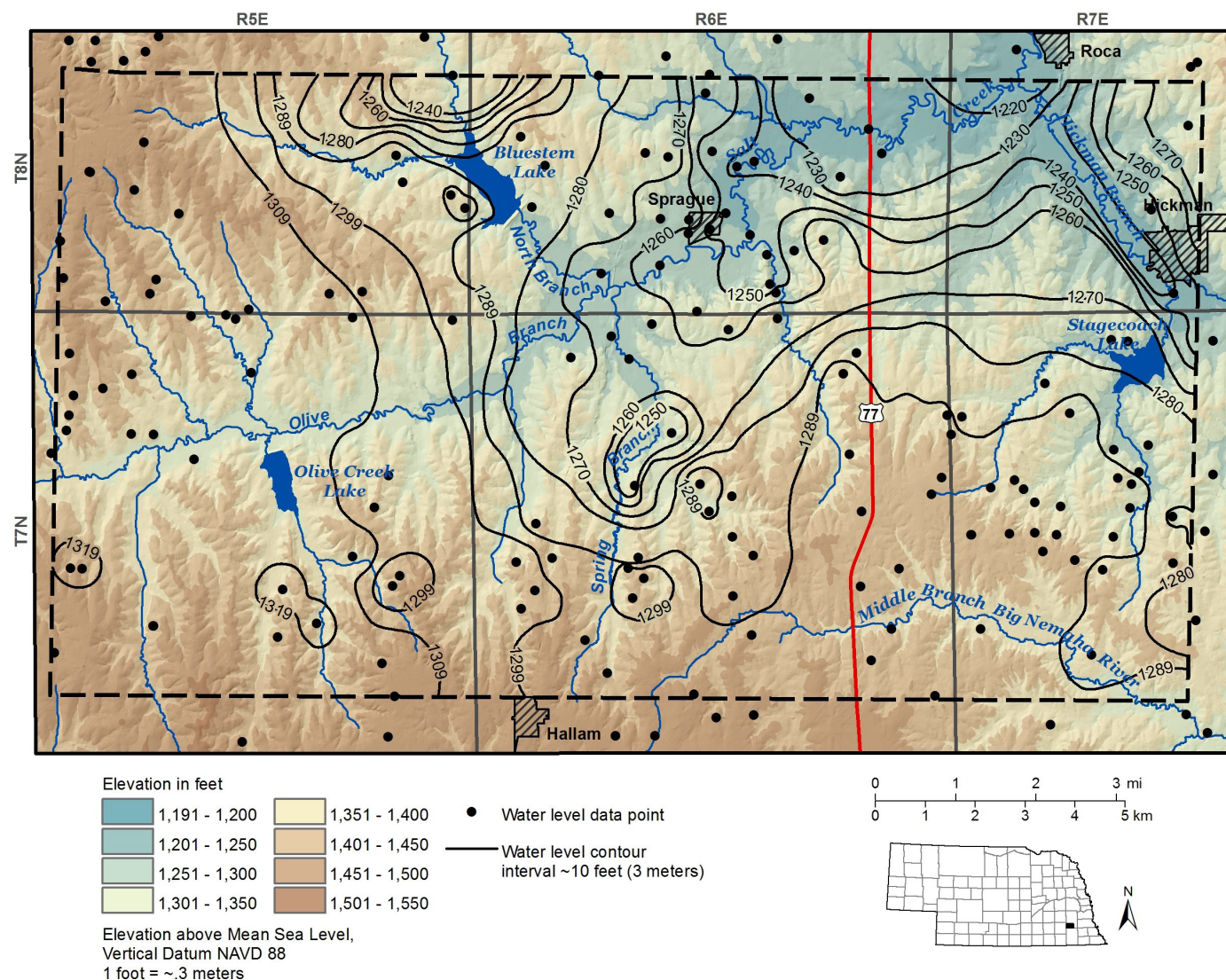


Figure 5. Generalized water table/potentiometric surface. Contours are based primarily on depth-to-water measurements collected by drillers from wells at the time of installation, which was between 1991 and 2011. Water levels in some wells may be inaccurate because screen intervals and gravel packs cross multiple lithologic units.



Many of the wells from which water levels were obtained contain a gravel pack that extends from the surface seal to the bottom of the well. This type of construction results in a connection between any water bearing units through which the well was drilled. The water levels in such wells are a composite of the hydraulic heads in each saturated unit. Saturated thickness estimates, which are based on the water level data, are therefore limited by the quality of the data.

The groundwater level contours on Figure 5 are potentially influenced by Spring Branch Creek and Salt

## Hydrostratigraphy

Relatively high resistivity materials (greater than 25 ohm-meters) are abundant in the study area. Two distinct layers of high resistivity separated by a layer of low resistivity are clearly evident in some profiles (e.g. line 20450 between 4-B-45 and 3-B-45; Fig. 4). As a result, two aquifer units (upper and lower) were outlined during interpretation of the HEM profiles. The elevation of the upper surface of each unit was used as criteria to distinguish it. We defined the upper aquifer material as the resistive unit with an upper surface at 400 meters (~1312 feet) above mean sea level or higher, and we defined the lower aquifer material as the resistive unit with an upper surface below approximately 400 meters.

On some profiles (e.g. line 20280) layering is not clear, but definition of the resistive material as a continuous

## Bedrock

The bedrock surface was defined almost entirely by borehole data because in all but the northeast corner of the study area the bedrock is too deep to be imaged by HEM. The methodology used to construct this surface was the same as that of Korus et al. (2012).

Figure 6 shows the estimated bedrock surface for the Sprague area. The elevation varies from a low of approximately 1053 feet to a high of approximately 1293 feet above mean sea level. The bedrock high in the eastern portion of the study area (T7N, R6E, S1) is based primarily on bedrock logged in one well only, though the log appears to be reliable. The one area of the bedrock surface defined by HEM is in the northwest corner of T8N, R6E, section 27, adjacent to Salt Creek. This portion of the bedrock surface (as defined by boreholes) was lowered to coincide with the bottom of the upper aquifer material.

Creek, indicating possible slight to moderate hydrologic connection between surface water and groundwater along portions of these creeks. The potential connection does not appear to exist on North Branch Creek or on any creek in the study area west of Spring Branch Creek.

Groundwater is extremely limited in the northeast portion of the study area due to shallow (or outcropping) bedrock, and no aquifers are mapped in that area. The water level contours there are constrained almost entirely by the surface water elevation.

upper or lower unit was not viable either. At these locations, we relied on our pre-defined criteria that a resistive surface occurring at approximately 400 meters above mean sea level or lower be defined as the lower aquifer material. In many locations this criteria lead to the upper and lower aquifer material being in direct contact with each other.

All other materials with resistivity values lower than approximately 25 ohm-meters are considered aquitards and have not been subdivided. That portion of the aquitard that separates the two aquifers is mapped as a local confining unit and will be discussed later.



*HEM survey being flown over a pasture in the Sprague study area.*

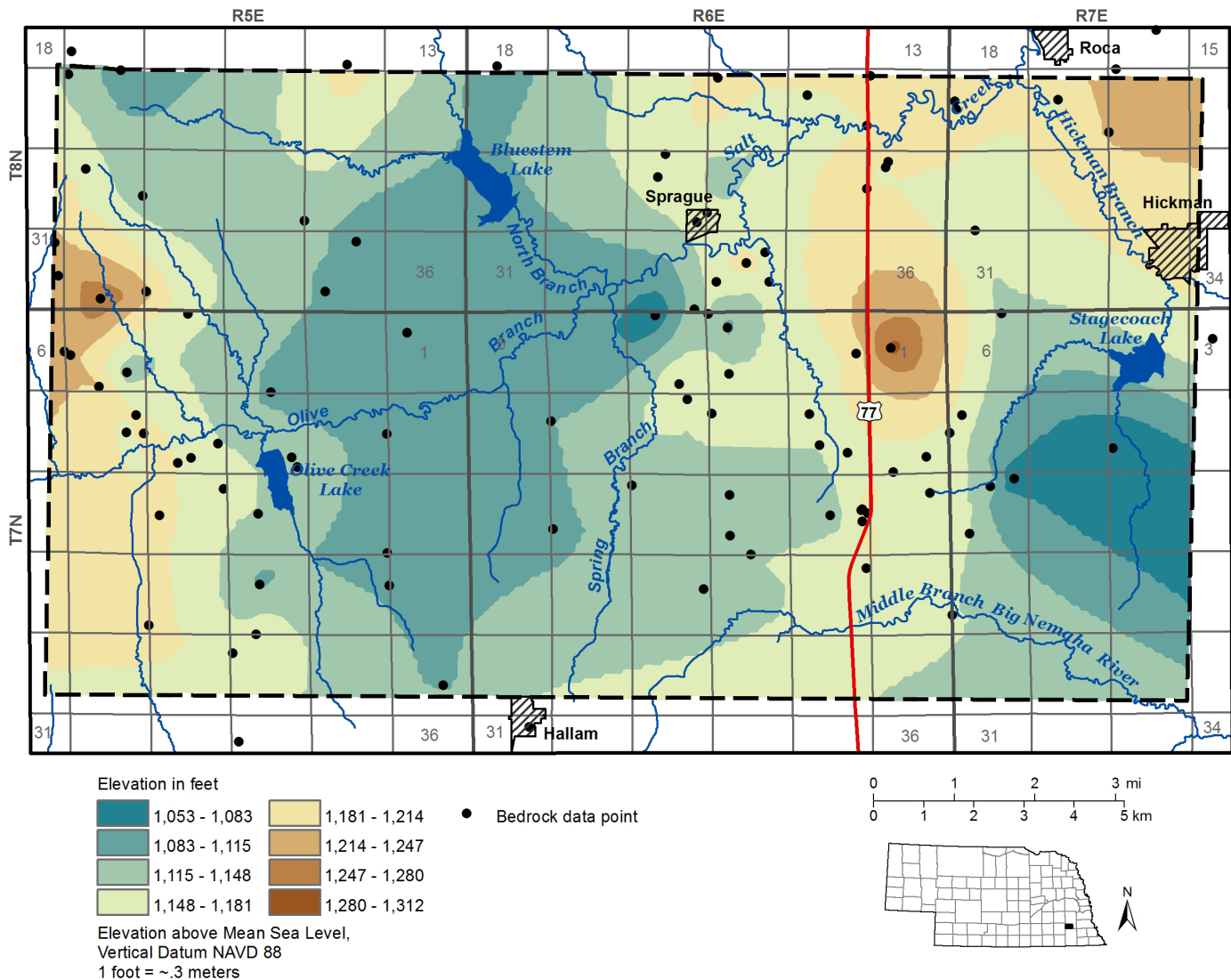


Figure 6. Elevation of the bedrock surface interpolated from test holes and registered wells. Relatively low bedrock elevation is shown in blue and relatively high bedrock elevation in brown.

Although regional trends of aquifer transmissivity (Summerside and Myers, 2005) and bedrock elevation (Conservation and Survey Division, 1980) suggest a west-east trending paleovalley, no well-defined, west-

east bedrock low is apparent across the study area. The geometry and fill of the paleovalley is probably more complex and locally variable than previously thought.

## Lower Aquifer Material

The lower aquifer material is identified on the basis of high resistivity values (generally greater than 25 ohm-meters) and verified by the occurrence of sands and gravels in test holes and registered well logs. The top of the lower aquifer is identifiable in most HEM profiles at a depth of approximately 400 m or lower, but in a few areas it lies below the maximum depth of HEM investigation. In those areas, correlations were made on the basis of borehole data. Lower aquifer material is present in south and west portions of the

study area and its top surface has approximately 260 feet of relief (Fig. 7).

The bottom of the lower aquifer was almost entirely below the maximum depth penetrated by HEM, and was imaged only in portions of eight flight lines. In all but this limited area, the top of bedrock elevation was substituted as the bottom elevation of the lower aquifer material (Fig. 8). Substituting bedrock for the base of the aquifer leads to an over-estimation of the

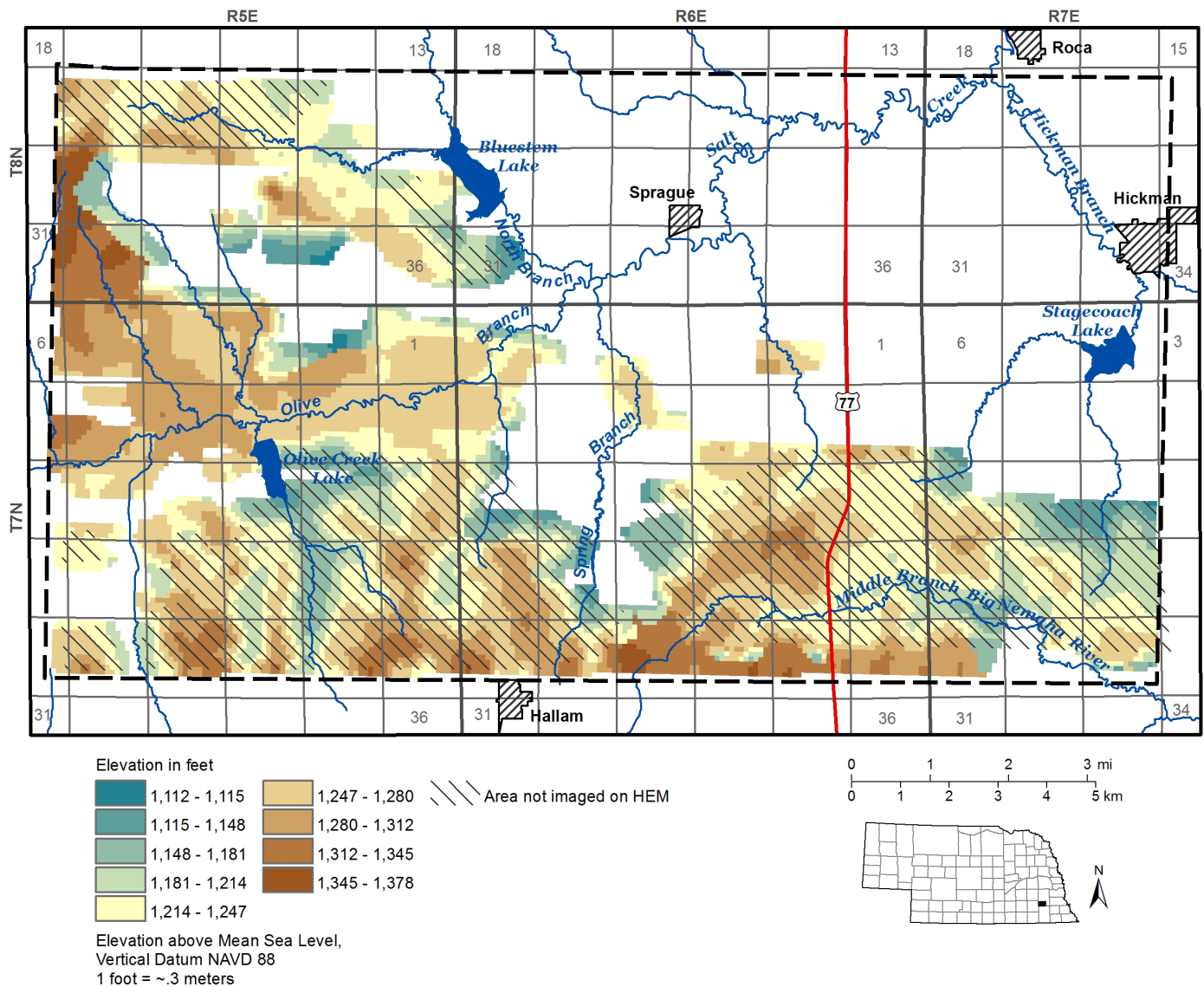


Figure 7. Elevation of the top of the lower aquifer material. Relatively low elevations are shown in blue, relatively high elevations shown in brown. Aquifer material is absent in portions of the survey area shown in white. Hatch marks indicate zones where the surface was drawn using lithologic logs only (no HEM).

thickness of the lower aquifer unit, as some fine-grained units of limited thickness and areal extent certainly exist above bedrock and below the lower aquifer (Korus et al., 2012). Not enough information exists, however, to map such units. The area under which the base of the lower aquifer was observed in the profiles lies mostly within the Olive Branch valley. The base of the aquifer in this area is comprised of fine-grained, unconsolidated materials above bedrock.

The lower aquifer material attains approximately 220 feet in maximum thickness (Fig. 9). It is absent in parts

of the south-central and northwest portions of the study area, where it appears to have been eroded and replaced by shallow aquifer or aquitard material. It is also absent in the northeast corner of the study area where bedrock is very shallow. The thickest portions of the lower aquifer material generally correspond to low elevations in the bedrock surface. The sharp decline in thickness in the northwest corner of the study area is due what the authors interpret as erosion during deposition of the upper aquifer material.







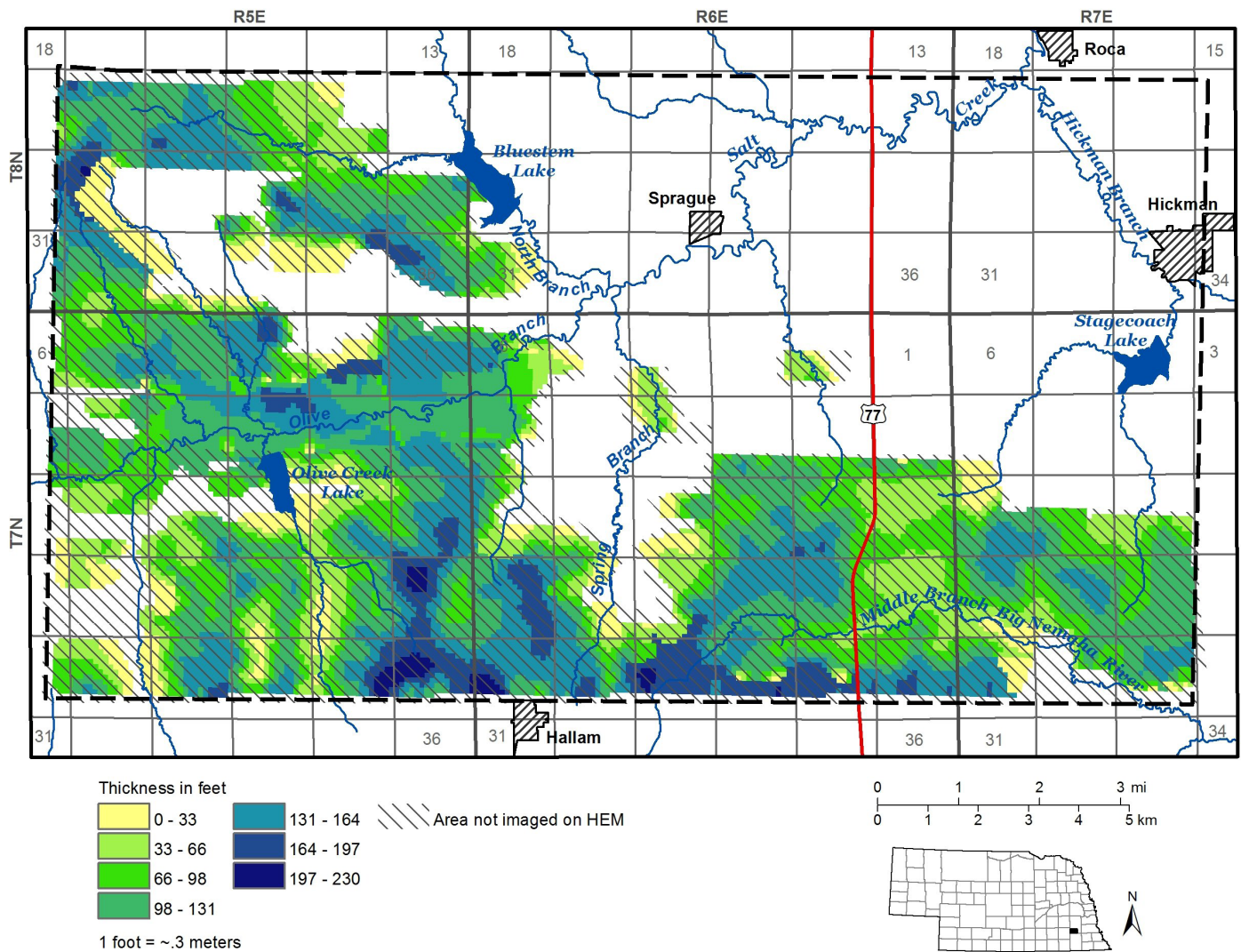


Figure 9. Thickness of lower aquifer material. Relatively thin zones are shown in yellow, relatively thick zones shown in blue.



Helicopter flying over power lines. The “bird” is about to emerge over the hill.

Similar to the Firth study area (Korus et al., 2012), we find that the lower aquifer is confined where it is overlain by till and is unconfined where it is in direct contact with the upper aquifer. In areas where it is unconfined, the aquifer is not saturated throughout its entire thickness. Although the maximum thickness of sands and gravels is approximately 220 feet, its maximum saturated thickness is 194 feet (Fig. 10). The partially saturated portions of the unit occur primary along the south and west margins of the study area.

The composition of sands and gravels as well as the elevations and geometries of its lower and upper surfaces suggest that the lower aquifer in the Sprague area is part of the same paleovalley sedimentary fill complex as the Firth study area (cf. Korus et al., 2012).



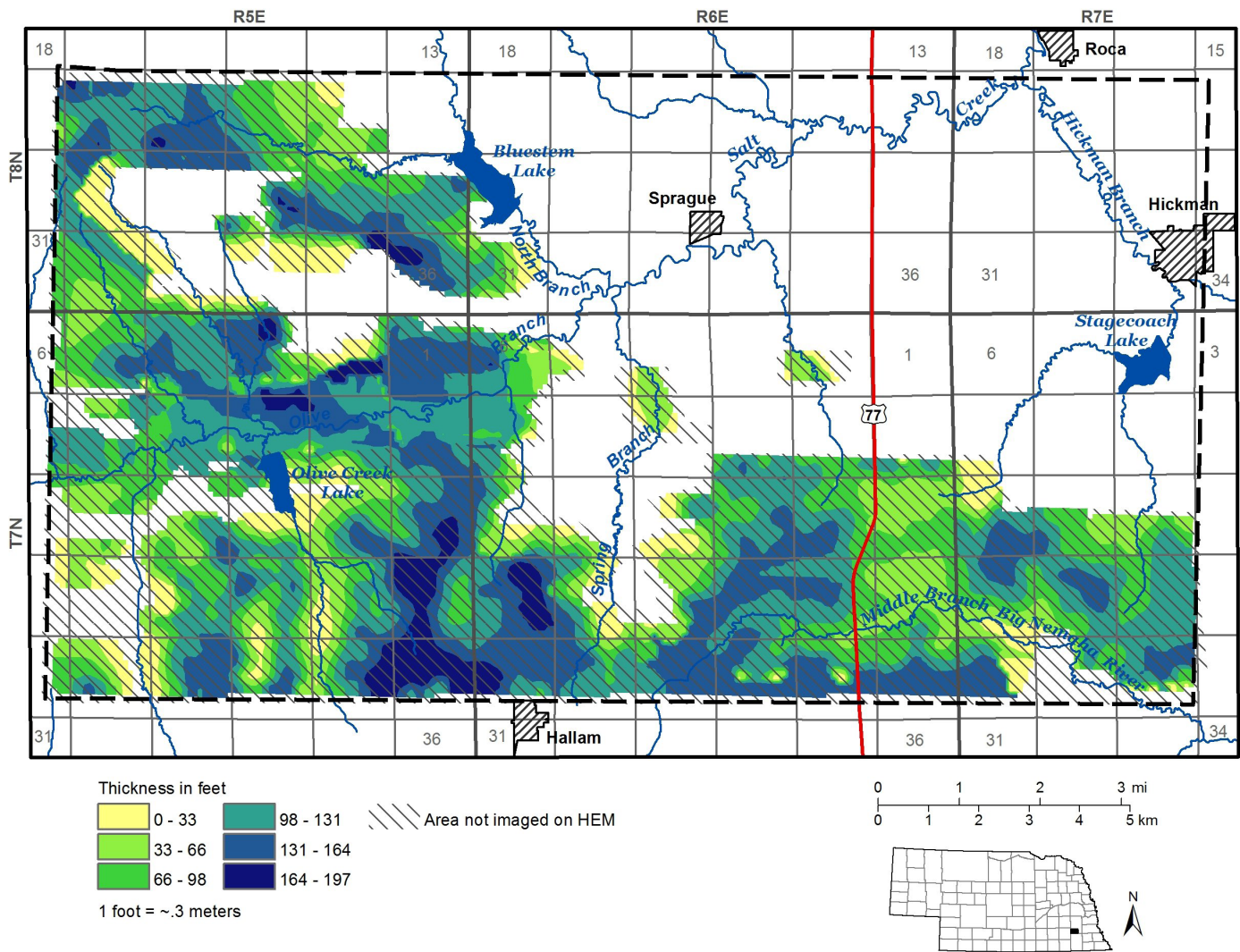


Figure 10. Saturated thickness of lower aquifer computed by subtracting the elevation of the bottom of the lower aquifer material (Fig. 8) from the elevation of the water table (Fig. 5). Relatively thin zones are shown in yellow, relatively thick zones shown in blue.



The helicopter used to fly the HEM survey.



## Upper Aquifer Material

The upper aquifer material is identified on the basis of high resistivity values (generally greater than 25 ohm-meters) and is identifiable in all of the HEM profiles. Portions of the upper aquifer material have slightly higher resistivity than the lower aquifer material penetrated by HEM, but the primary distinguishing characteristic was elevation (Fig. 4). The upper aquifer material is present over much of the study area and its upper surface has approximately 260 feet of relief, which is strongly shaped by topography (Fig. 11). The top of the upper aquifer material is generally highest in an upland area between North Branch Creek and a tributary of Olive Creek in T8N, R5E.

The bottom of the upper aquifer is identifiable in nearly all of the HEM profiles, though it was estimated in a few profiles (Fig. 12). The bottom of the upper aquifer material is generally lowest in the same areas where the elevation of its upper surface is highest.

The thickest part of the upper aquifer material occurs in the northwest portion of the study area between North Branch and a tributary of Olive Branch (mostly in T8N, R5E), although there are a few thick spots in the south central tip of the shallow aquifer material (T7N, R6E) and south of the Middle Big Nemaha River (Fig. 13). The thickest portions of the upper aquifer material

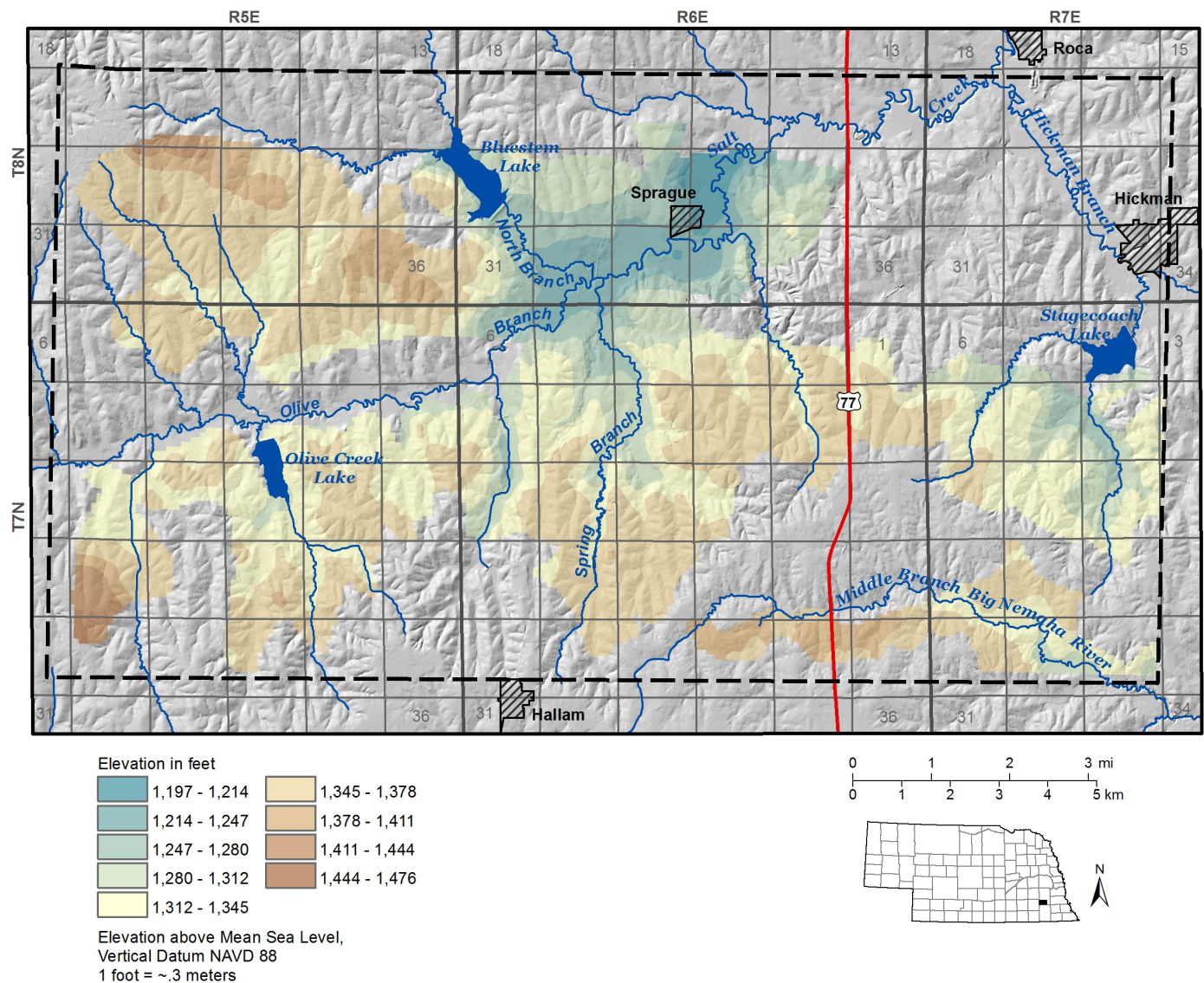


Figure 11. Elevation of the top of the upper aquifer material. Relatively low elevations are shown in blue, relatively high elevations shown in brown. Aquifer material is absent in uncolored portions of the survey area. Topographic relief appears in the background to demonstrate that the top surface of the upper aquifer material strongly, but not completely, coincides with topography.

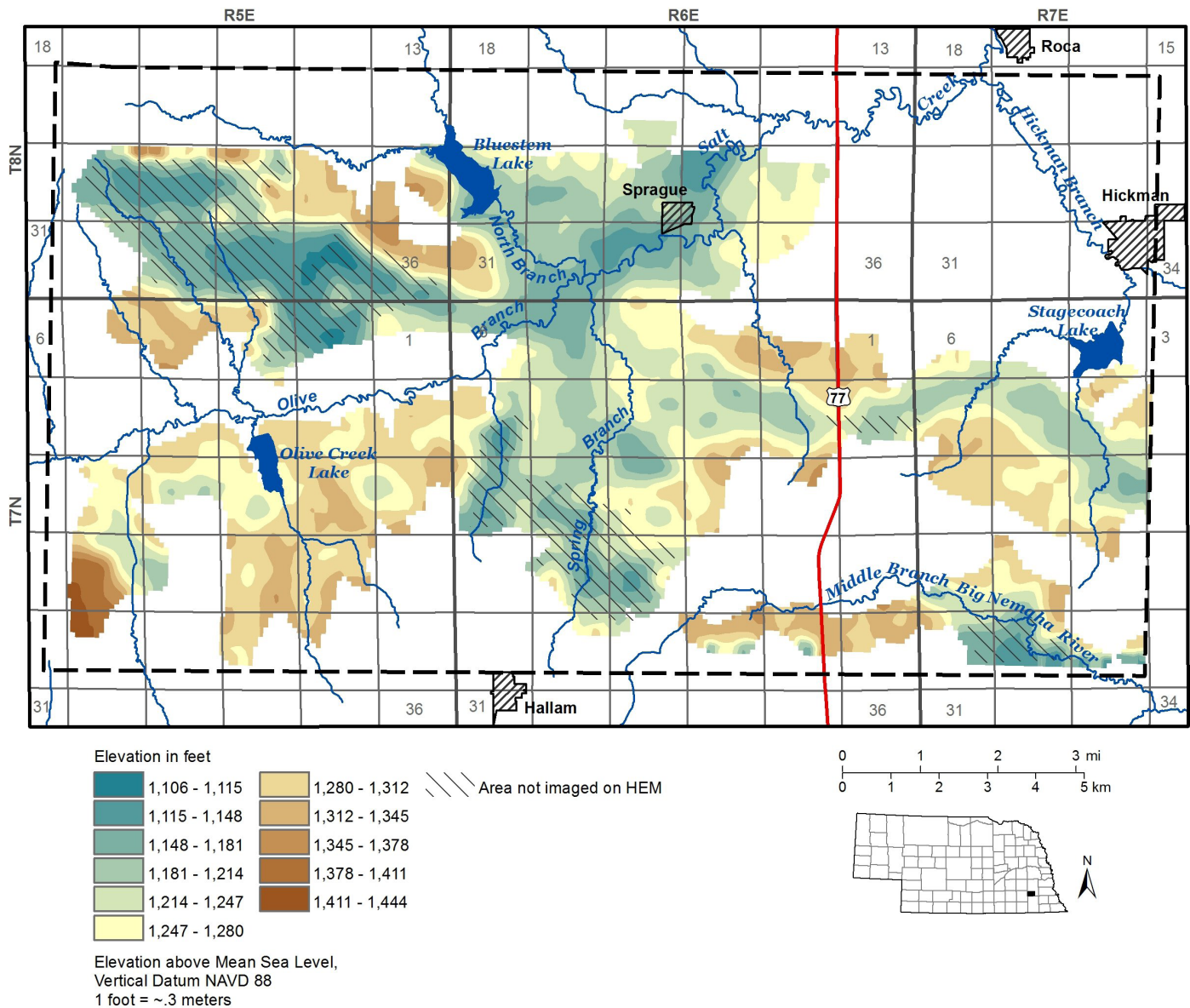


Figure 12. Elevation of the bottom of the upper aquifer material. Relatively low elevations are shown in blue, relatively high elevations shown in brown. Aquifer material is absent in portions of the survey area shown in white. Hatch marks indicate zones where the surface was drawn using lithologic logs only (no HEM).



The HEM survey is conducted around the Sheldon power plant near Hallam, Nebraska.

correspond to areas where the lower aquifer material has been eroded. The upper aquifer material itself has been eroded in places by present-day creeks, and is completely eroded by Olive Branch. The thickness of the upper aquifer material varies from zero to approximately 280 feet, significantly thicker than in the Firth study area, where it varied from zero to approximately 185 feet thick.

In addition to being thicker, the shallow aquifer material mapped in the Sprague area is much more wide-spread than in the Firth study area, where it is primarily present as a 0.4 – 1.4 mile wide east-west elongated sand body. The elongate geometry of the shallow aquifer material at Firth continues into the eastern portion of the



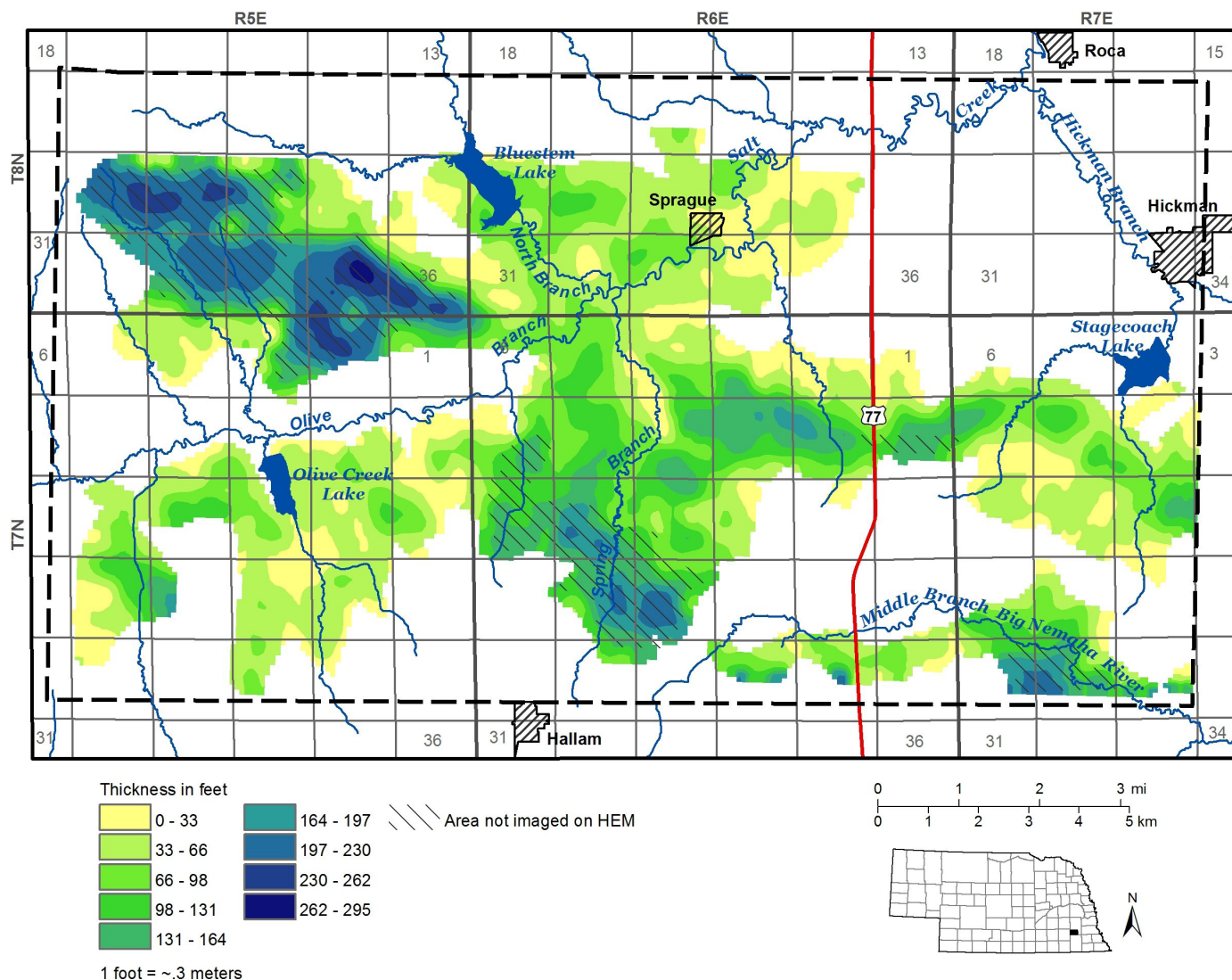


Figure 13. Thickness of upper aquifer material. Relatively thin zones are shown in yellow, relatively thick zones shown in blue.



HEM survey being flown over a pasture in the Sprague study area.

Sprague study area, where it appears to be somewhat constrained by bedrock geometry (near section 12, T6N, R6E). The lower aquifer material is absent in this area, and the elongate shape of the shallow aquifer material corresponds to a depression in the bedrock surface. The sand body also appears to narrow as it passes through two high points on the bedrock surface, and then widens considerably on the western side of the bedrock highs. In terms of the overall physical setting of the area, the upper aquifer materials are best classified as stratified sands associated with glacial deposits.

Much of the peripheral portions of the upper aquifer material are not saturated (Fig. 14). The maximum saturated thickness of the unit is approximately 200 feet, with thick saturated areas corresponding to areas where the aquifer material itself is thick.

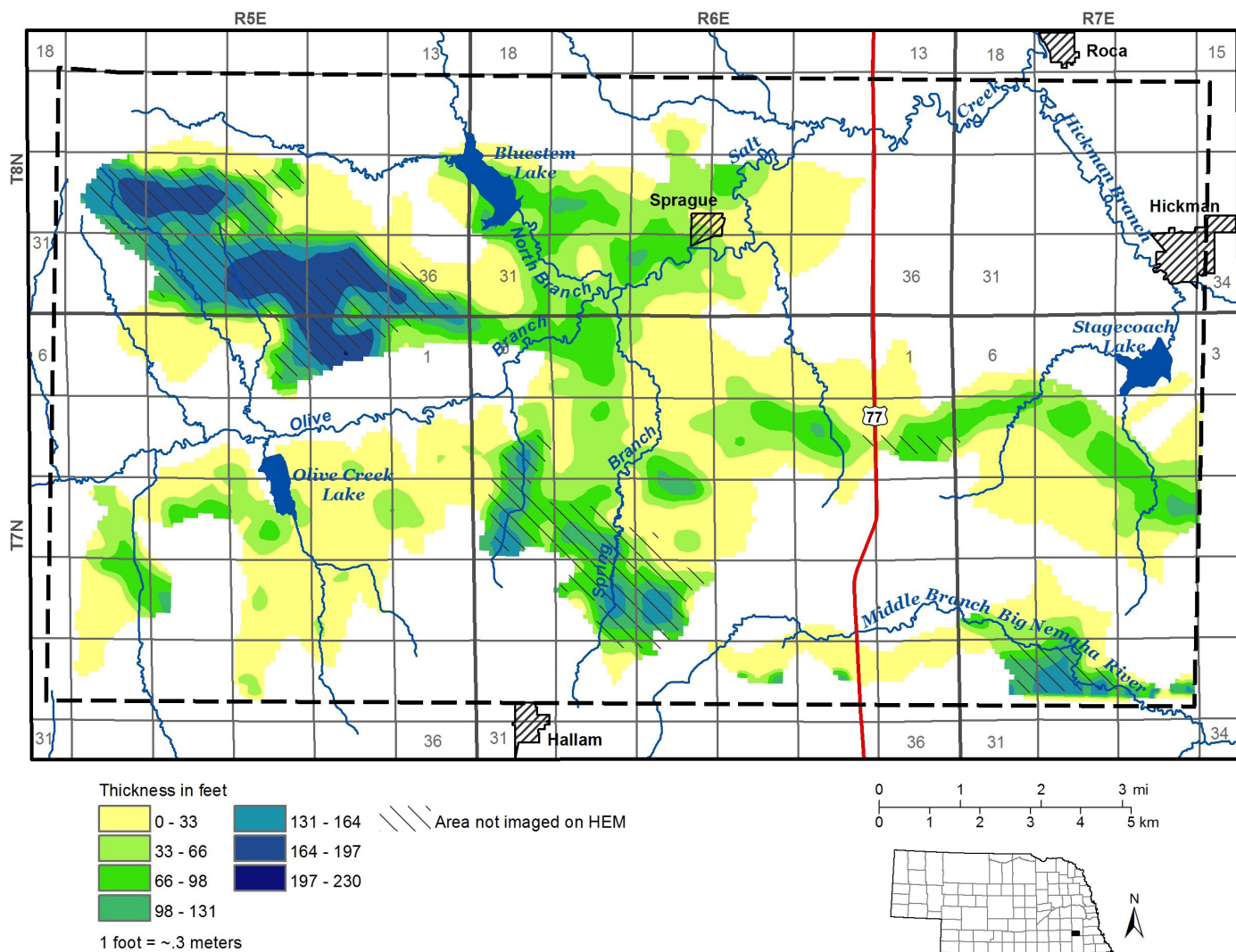


Figure 14. Saturated thickness of upper aquifer computed by subtracting the elevation of the bottom of the upper aquifer material (Fig. 12) from the elevation of the water table (Fig. 5).. Relatively thin zones are shown in yellow, relatively thick zones shown in blue.



HEM survey being conducted near the Sheldon power plant north of Hallam, Nebraska.



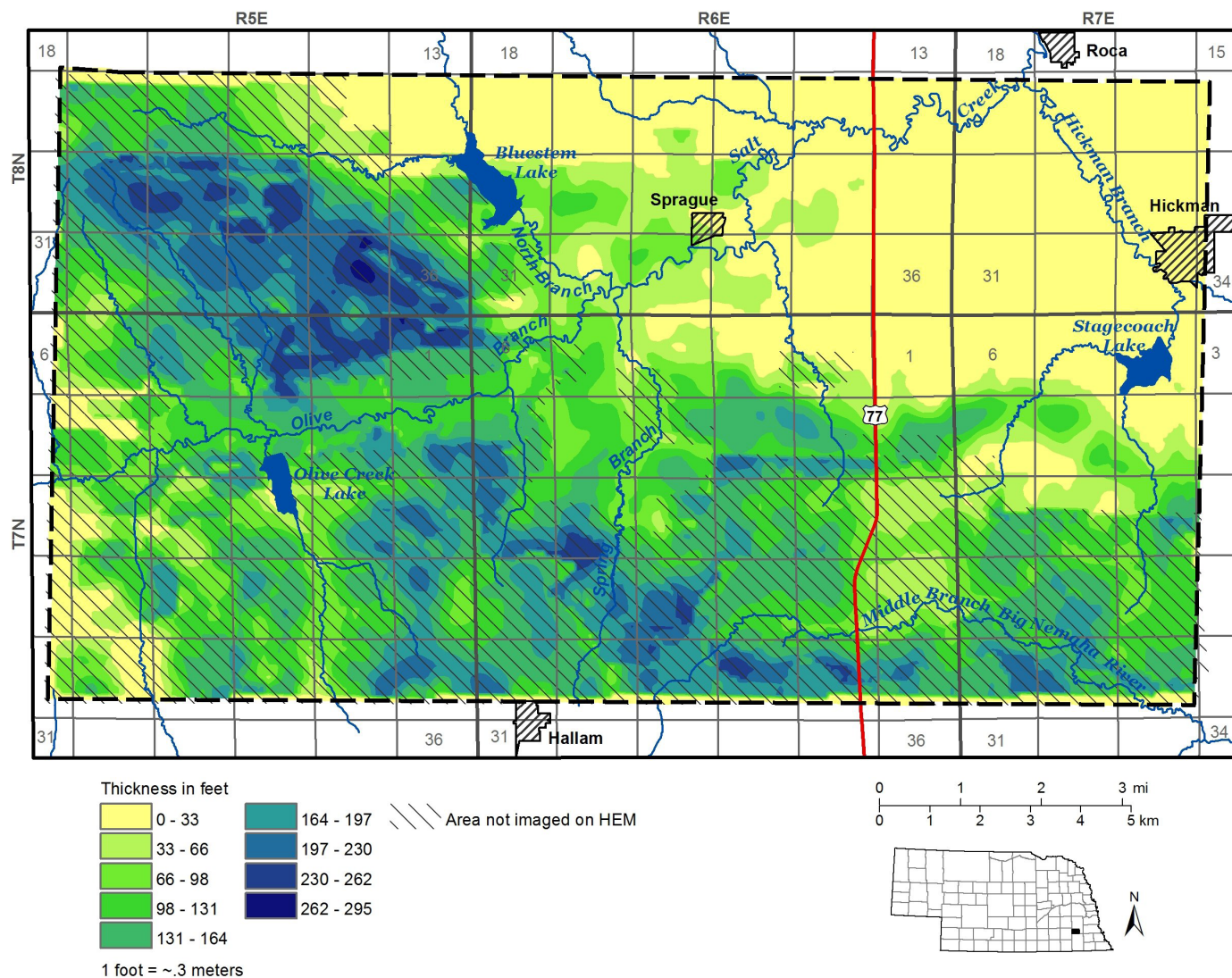


Figure 15. Total thickness of aquifer material. This map represents the summation of the thicknesses of the upper and lower aquifer materials. Any aquitard material that separates the two units is not included in the total. Relatively thin zones are shown in yellow, relatively thick zones shown in blue.

## Aquifer Connections

Though the upper and lower aquifers were defined separately during the interpretation of the HEM profiles, in many locations in this study area they are in contact with one another and function as a single aquifer (Fig. 4, Lines 20110 and 20280). Figures 15 and 16 show the total thickness (0 to 280 feet) and the total saturated thickness (0 to 260 feet) of the aquifers, respectively. Some of the linear/irregular features in the figures are the result of superimposing the thicknesses of two separate units. Even in locations where the two aquifers are not in direct contact with one another, knowing the total saturated thickness is important because historical well construction practices have effectively linked the two units within the well annulus.

Figure 17 depicts the areas in which the upper and lower aquifer units are separated by a fine-grained unit. This confining unit ranges from 0 to 187 feet thick. The thickness of the confining unit was calculated by subtracting the elevation of the top of the lower unit from the elevation of the bottom of the upper unit. This confining unit is shown only where it exists between the two aquifers. It is present mostly around the thin margins of the upper aquifer (Fig. 4, Lines 02080 and 20450). The thickest and most extensive part of the confining unit is located in an approximately 6 square mile area in T7N, R5E.

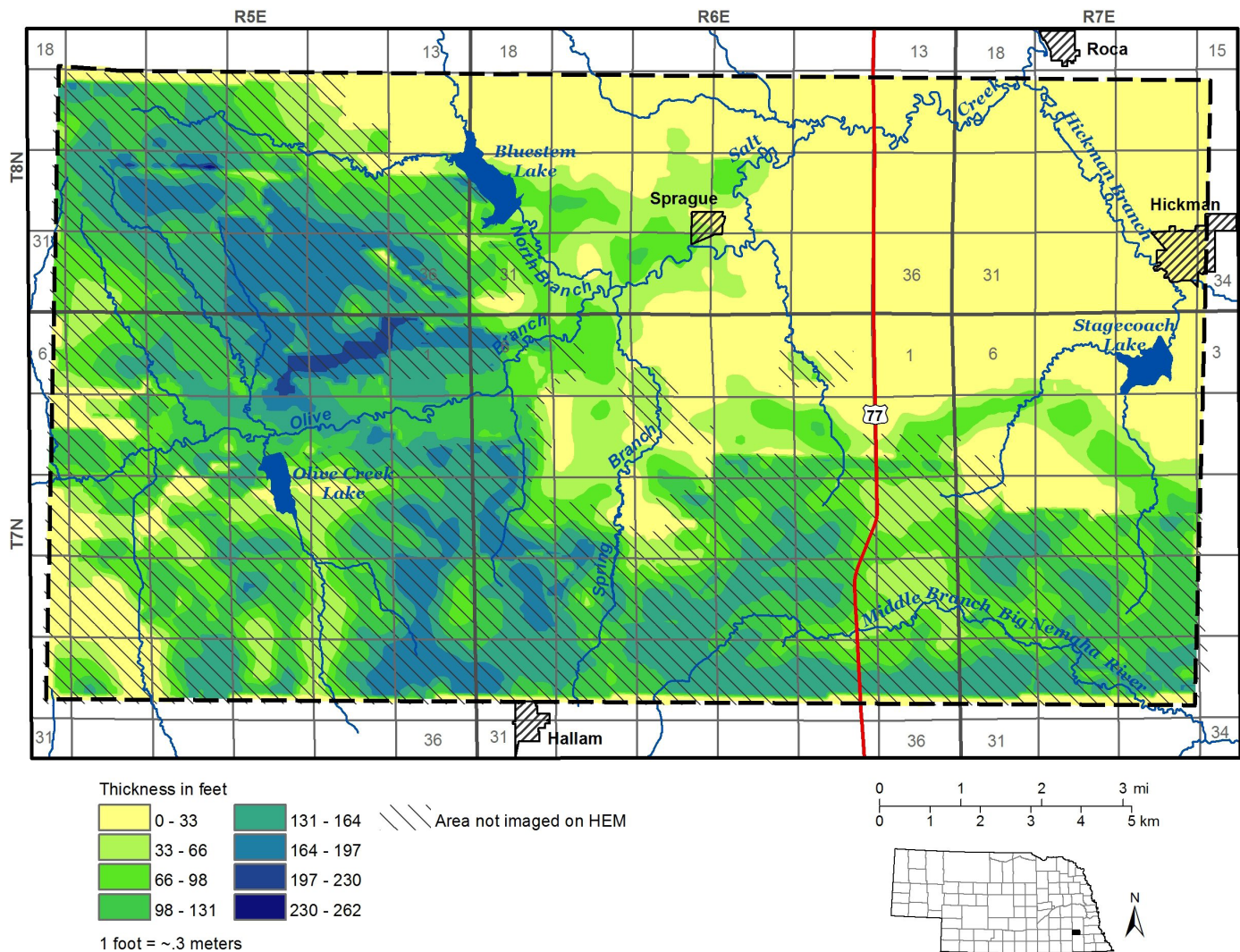


Figure 16. Total aquifer thickness. This map represents the summation of the saturated thicknesses of the upper and lower aquifers. Saturated aquitard material that may separate the two units is not included in the total. Relatively thin zones are shown in yellow; relatively thick zones shown in blue.

## Areas of Potential Recharge/Vulnerability

Groundwater recharge and vulnerability to contamination are controlled by many factors, such as precipitation, depth to the water table, and the hydraulic conductivity of materials above the water table. Determining these characteristics was beyond the scope of this study, but the thickness of saturated and unsaturated fine-grained materials (silt, clay, till) that exist above the aquifer can be used as a first approximation of groundwater vulnerability. Figure 18 depicts areas where fine-grained units are thin or absent above the aquifer. The figure was

made by combining the top of the upper aquifer with the top of the lower aquifer to make one surface representing the top of the shallowest aquifer. The elevation of that surface was then subtracted from land surface elevation to give the thickness of fine grained deposits above the uppermost coarse-grained unit. Figure 18 suggests that, on the basis of aquitard thickness in the study area, hillslopes adjacent to ephemeral or perennial drainages tend to be the sites of highest potential recharge and vulnerability to contamination.



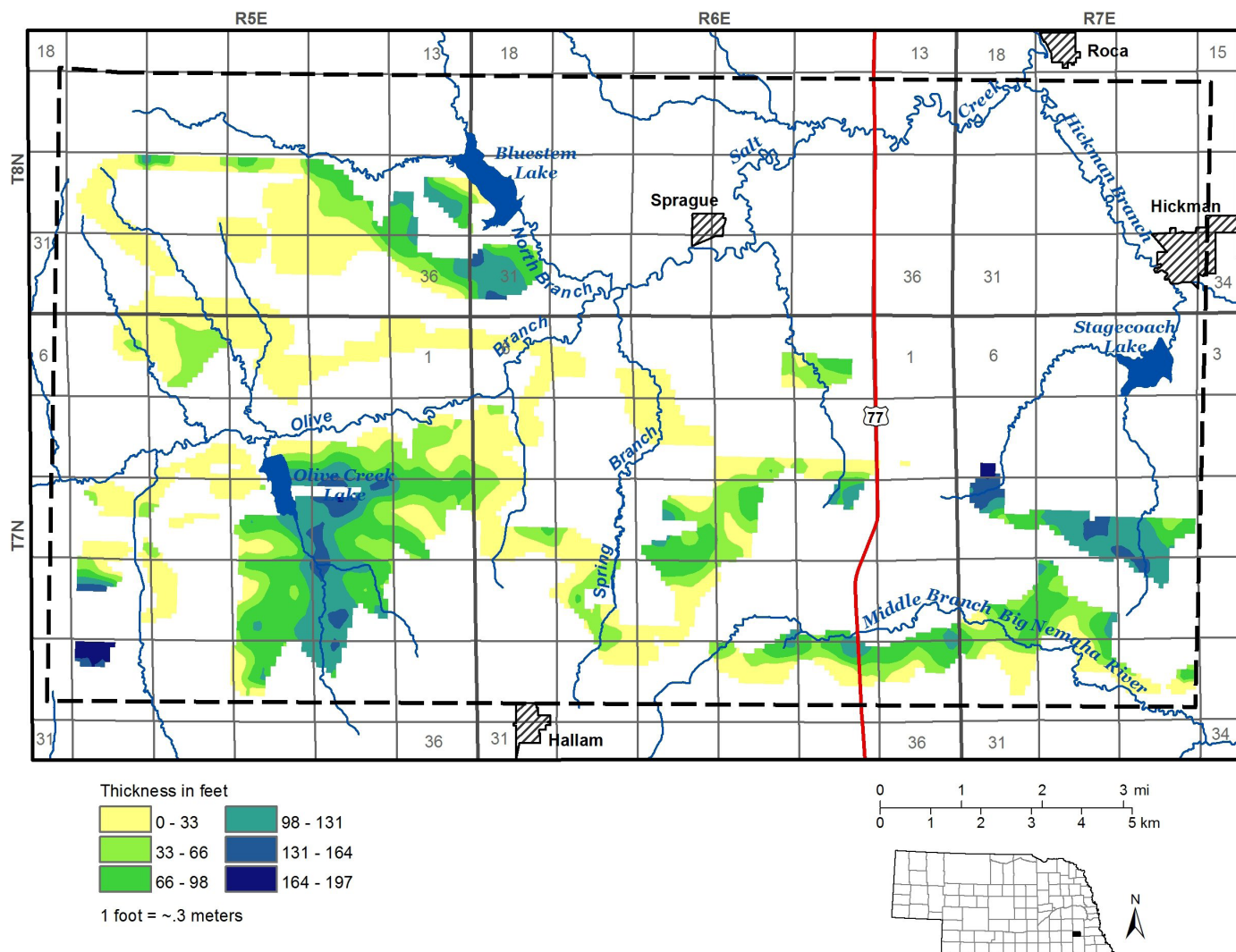


Figure 17. Confined areas of lower aquifer. Colored zones represent locations where deposited confining unit exists between the upper and lower aquifers. Relatively thin aquitard shown in yellow, thicker aquitard shown in blue.

## Hydrologically Connected Surface Water and Groundwater

The combined water table/potentiometric surface map (Fig. 5) indicates that Salt Creek and Spring Branch Creek may have some hydrologic connection to groundwater. Hydrostratigraphic profiles were made under each of these creeks to further investigate the potential degree of connection. The grids used to construct the profiles had 100 meter square cells, so the profiles must be viewed as estimates only. The Olive Branch/Salt Creek profile (Fig. 19) starts at the west edge of the flight area and progress towards the northeast corner of the study area where

it converges with Hickman Branch. The lower aquifer material is present in the west half of the profile and the upper aquifer material is present in the east half, but they pass fairly seamlessly into one another along the profile and no distinction is made in Figure 19. The aquifers appear to have very limited connection to the creek, with the top of the aquifers generally about 30 feet below land surface. The exceptions are two points where the aquifer comes within approximately 10 feet of the land surface and two points where the aquifer appears to intersect the

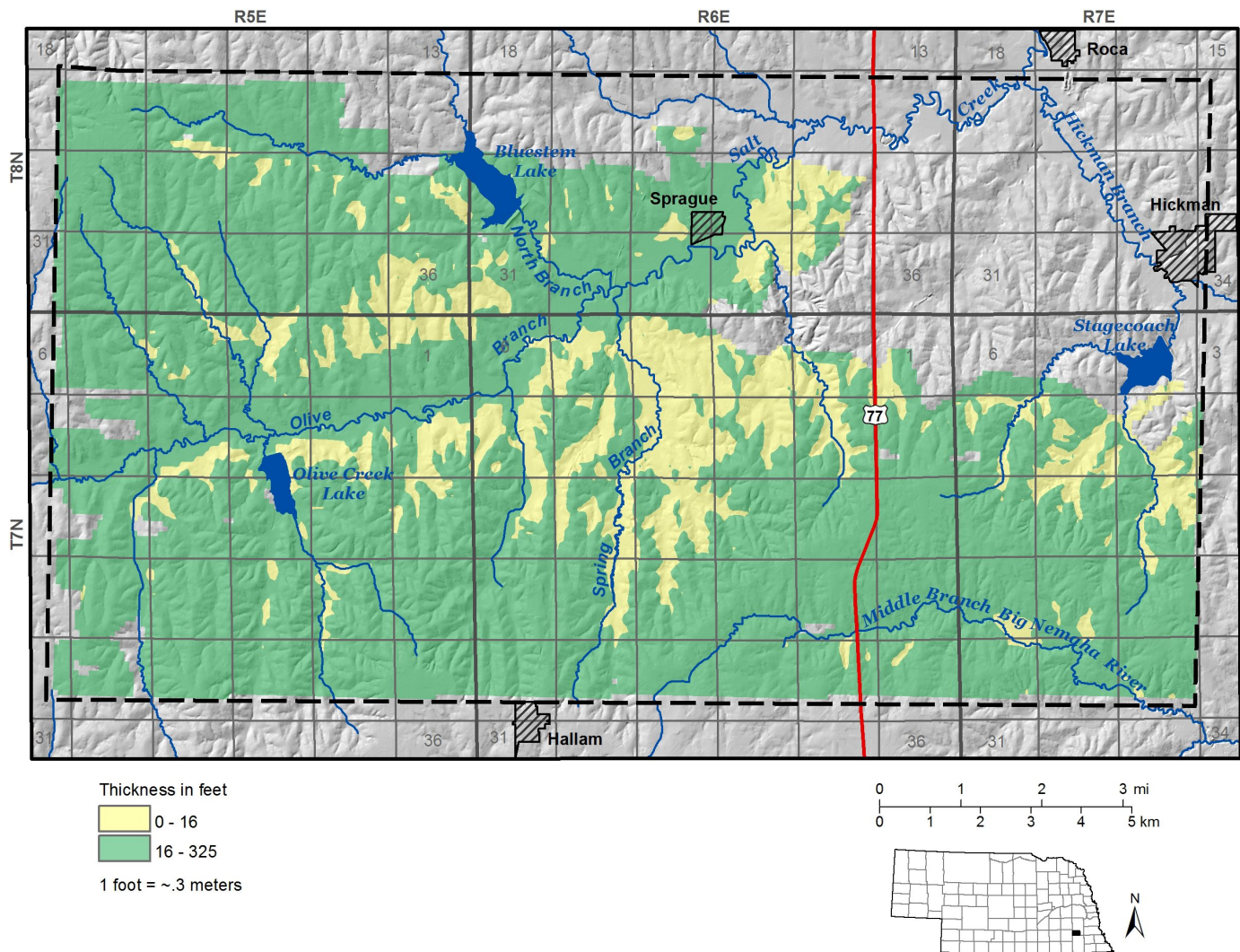


Figure 18. Potential recharge areas vulnerable to contamination. This map shows the locations where the fine-grained material above the upper aquifer material is five meters (16 feet) thick or less. Topographic relief appears in the background to demonstrate to the relationship between topography and thickness.

land surface. The water table/potentiometric surface is generally at or above the level of the stream in those locations, indicating that if hydrologic connection does exist, under average groundwater conditions, Salt Creek would likely be gaining.

The Spring Branch Creek profile (Fig. 20) starts at the south edge of the flight area and progresses north to converge with Olive Creek/Salt Creek. On this profile, the lower and upper aquifers are distinctly separated and

the upper aquifer material appears to be in close (~10 feet) or direct connection with the land surface for a total of approximately 2.5 miles along the profile. The water table/potentiometric surface is generally below the level of the stream, indicating that under average groundwater conditions, Spring Branch Creek is a losing creek in the places where hydrologic connection exists.

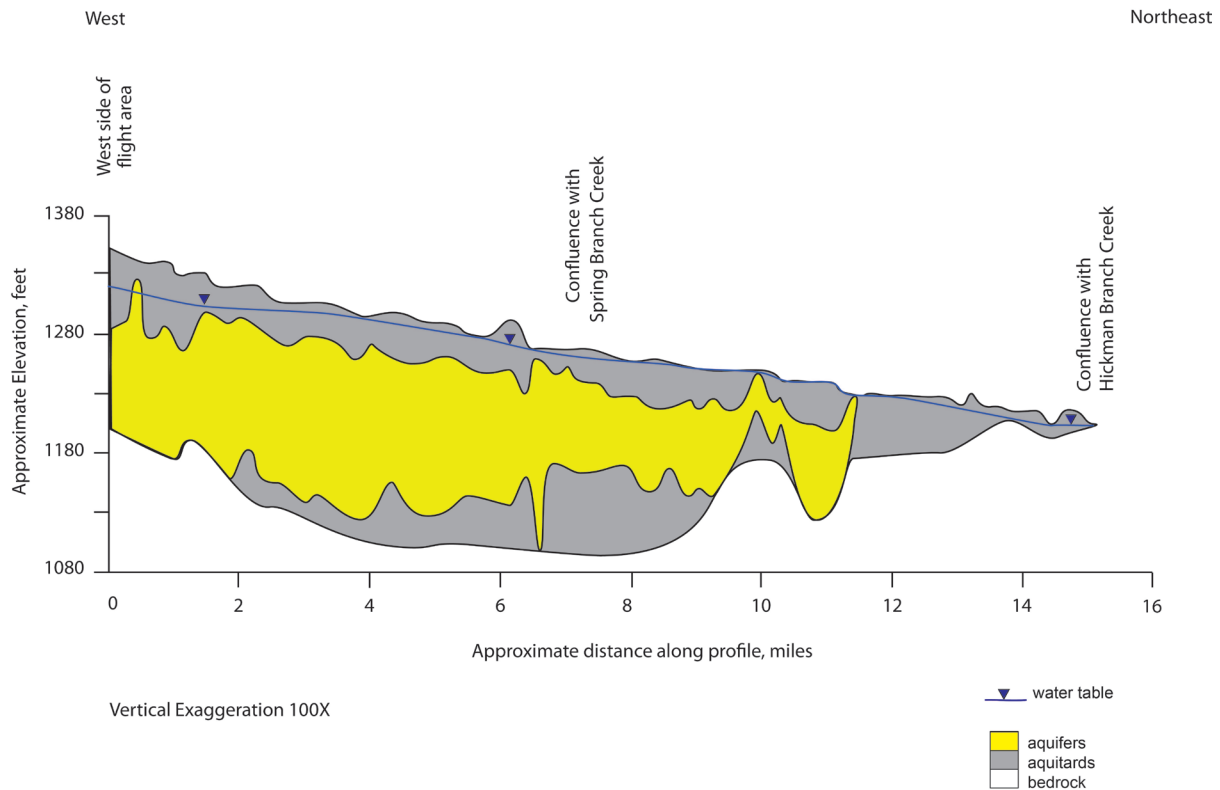


Figure 19. Hydrostratigraphic profile under Olive Branch and Salt Creek. This figure depicts the combined upper and lower aquifer material in relation to fine-grained material and the ground surface under Olive Branch and Salt Creek. A profile of the water table/ potentiometric surface is also shown. The diagram illustrates the very limited nature of contact between aquifer material and the ground surface.

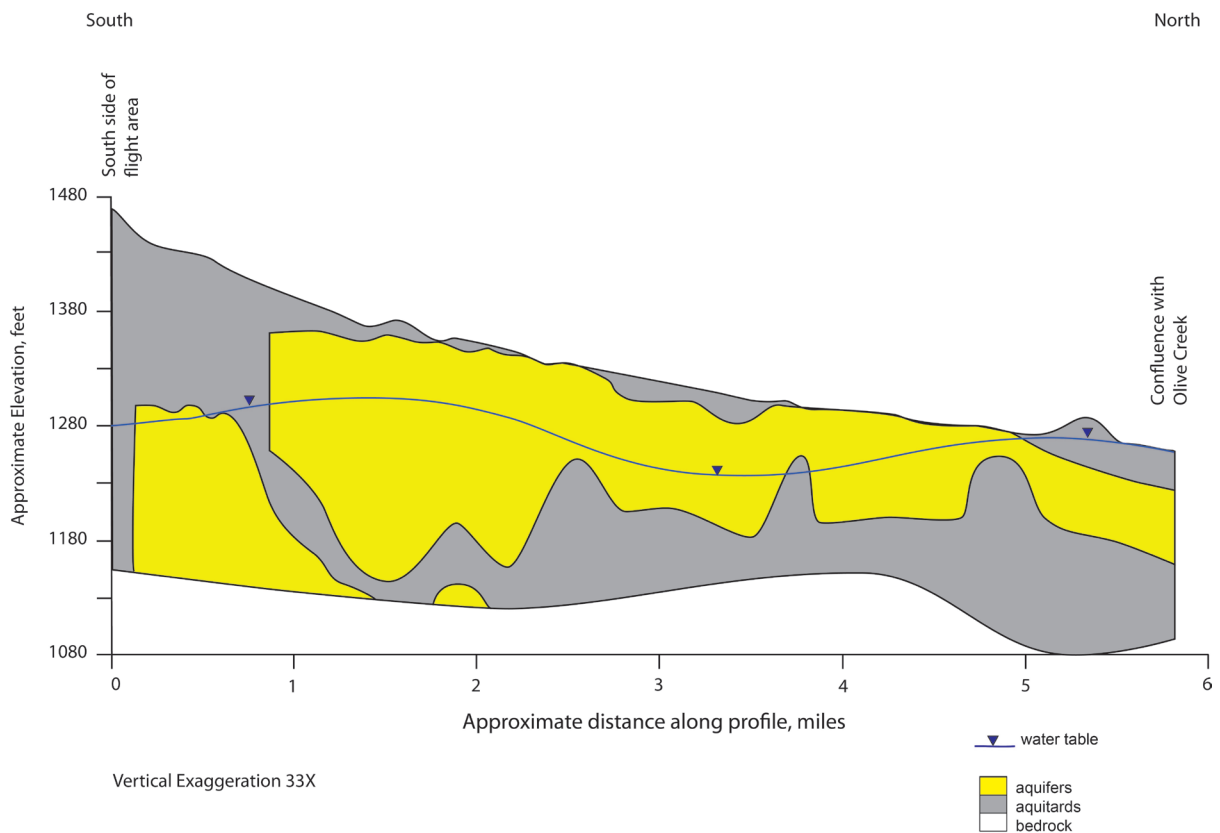


Figure 20. Hydrostratigraphic profile under Spring Branch Creek. This figure depicts the upper and lower aquifer material in relation to fine-grained material and the ground surface under Spring Branch Creek. A profile of the water table/ potentiometric surface is also shown. The top of the upper aquifer material is at or near the ground surface along approximately half of the transect, but the stream appears to be losing over most of this reach.



# DISCUSSION

## Implications for Resource Managers

Resource managers seek not only to preserve the quantity and quality of groundwater, but to identify areas where groundwater and surface water are hydrologically connected. In Nebraska, hydrologically connected areas are important because they are (or likely will be) managed to comply with Integrated Management Plans, whereas groundwater not in hydrologic connection with surface water can be managed according to the NRD Groundwater Management Plans. Given those goals, this study has two important implications for resources managers.

First, the upper and lower aquifer units in the Sprague study area are connected in many areas, and as a result, the lower aquifer unit exists under both confined and unconfined conditions. In places where the lower aquifer

unit is confined, it is less vulnerable to contamination than the shallow aquifer. Hickman Well 3 is an example of this condition, as suggested from a recent aquifer test and sampling. However, confined conditions do not exist everywhere, and is particularly variable west of Highway 77.

Second, the aquifers may have very limited hydrologic connection to Salt Creek. If any connect exists, Salt Creek would likely gain groundwater at those locations under average groundwater conditions. Spring Branch Creek is likely hydrologically connected along about half of its length, though the connection is to the upper aquifer material only and the creek probably loses water to the groundwater under average conditions.

## Potential for Future Work

The focus of this report is the three-dimensional geologic framework, namely the extent and thickness, of hydrostratigraphic units. Estimating the aquifer yield to prevent overdevelopment would require estimates of hydraulic conductivity and recharge rates as well. Estimates of the hydraulic conductivity in the study area could be calculated from the existing transmissivity maps (Summerside and Meyers, 2005) and registered well data, or could be measured by conducting aquifer tests. The recharge rates can be estimated using a variety of techniques including groundwater age dates (e.g. Steele et al., 2005); isotopic ratios (e.g. Gates et al.,

2008); field equipment such as heat dissipation probes and lysimeters (e.g. Bristow et al., 1993; Scanlon et al., 2002); and calculations using parameters such as base recharge and climatic data (e.g. Szilagyi et al., 2005).

In areas where water quality questions exist, nested monitoring wells that are sampled quarterly and equipped with pressure transducers would likely provide insight to groundwater flow paths and water chemistry. Salinity issues around the town of Princeton could be investigated with such a strategy.

# CONCLUSIONS

The primary goal of this study was to better understand the hydrostratigraphic framework in the vicinity of Sprague, Nebraska, which overlies the western portion of the Crete-Princeton-Adams Groundwater Reservoir of the Lower Platte South Natural Resources District. The framework presented herein can be used to address groundwater quality and quantity issues in this area. The bedrock surface elevation and geometry of the lower aquifer material indicate that the paleovalley is not a continuous west-east feature through the study area as previously thought. Rather, the bedrock surface consists of a series of more-or-less north-south trending highs and lows. The sedimentary fill of the paleovalley is complex. Sand and gravel bodies comprising the lower aquifer are discontinuous and their thicknesses are

highly variable. In some areas the entire thickness of the paleovalley fill appears to have been removed by erosion beneath overlying, channelized deposits. Materials comprising the upper aquifer are also highly complex. These shallow sands are much more wide-spread west of Highway 77 and are in hydraulic connection with the underlying lower aquifer throughout much of this area. This area therefore has a higher potential for groundwater recharge and greater vulnerability to contamination than areas east of Highway 77. Another important implication of this study is that Spring Creek is likely in hydraulic connection with the upper aquifer material for approximately half of its length. Future work could include estimating aquifer yield and installing nested monitoring wells to address water quality questions.

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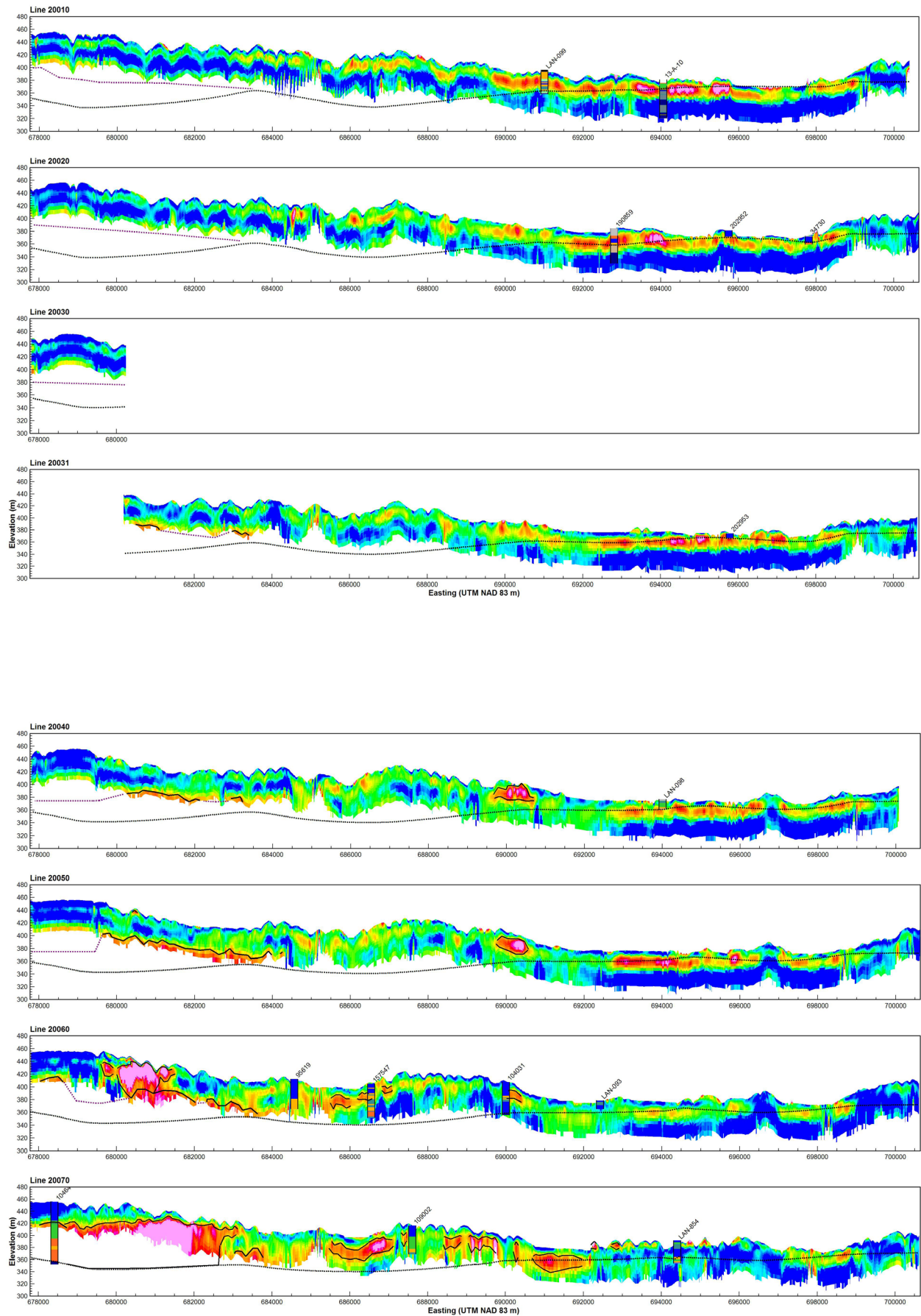
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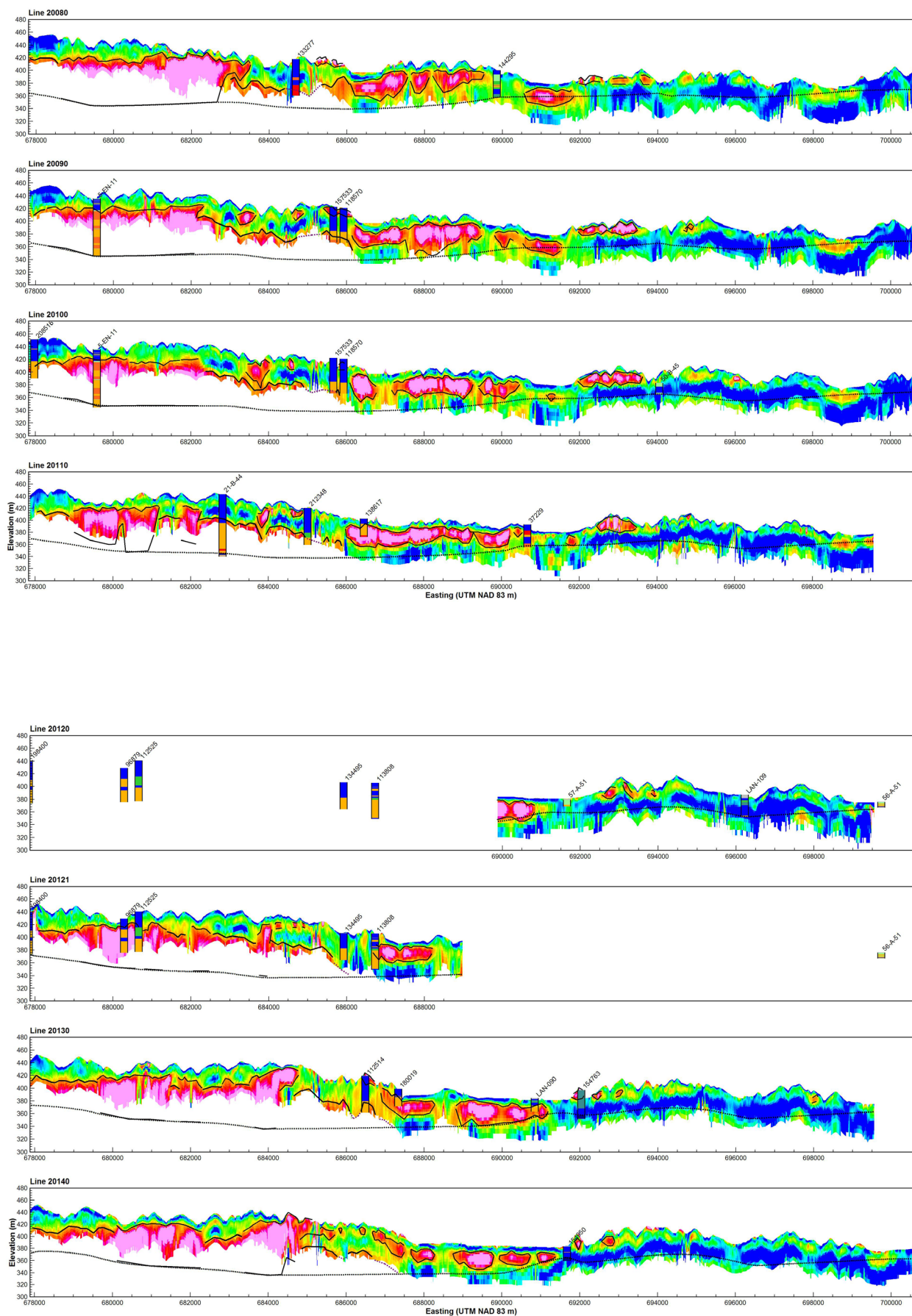
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# APPENDIX A

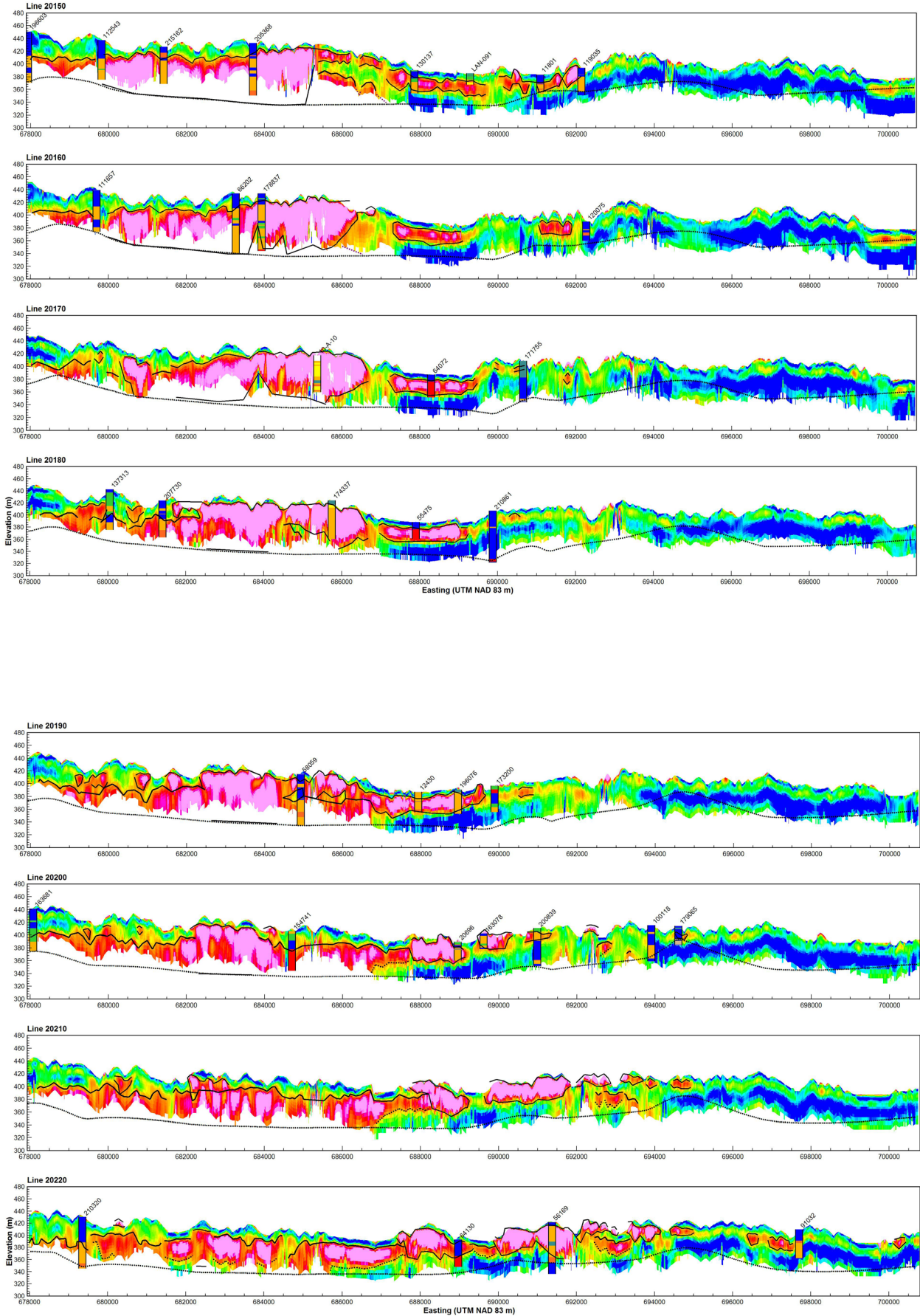
## West to East Profiles



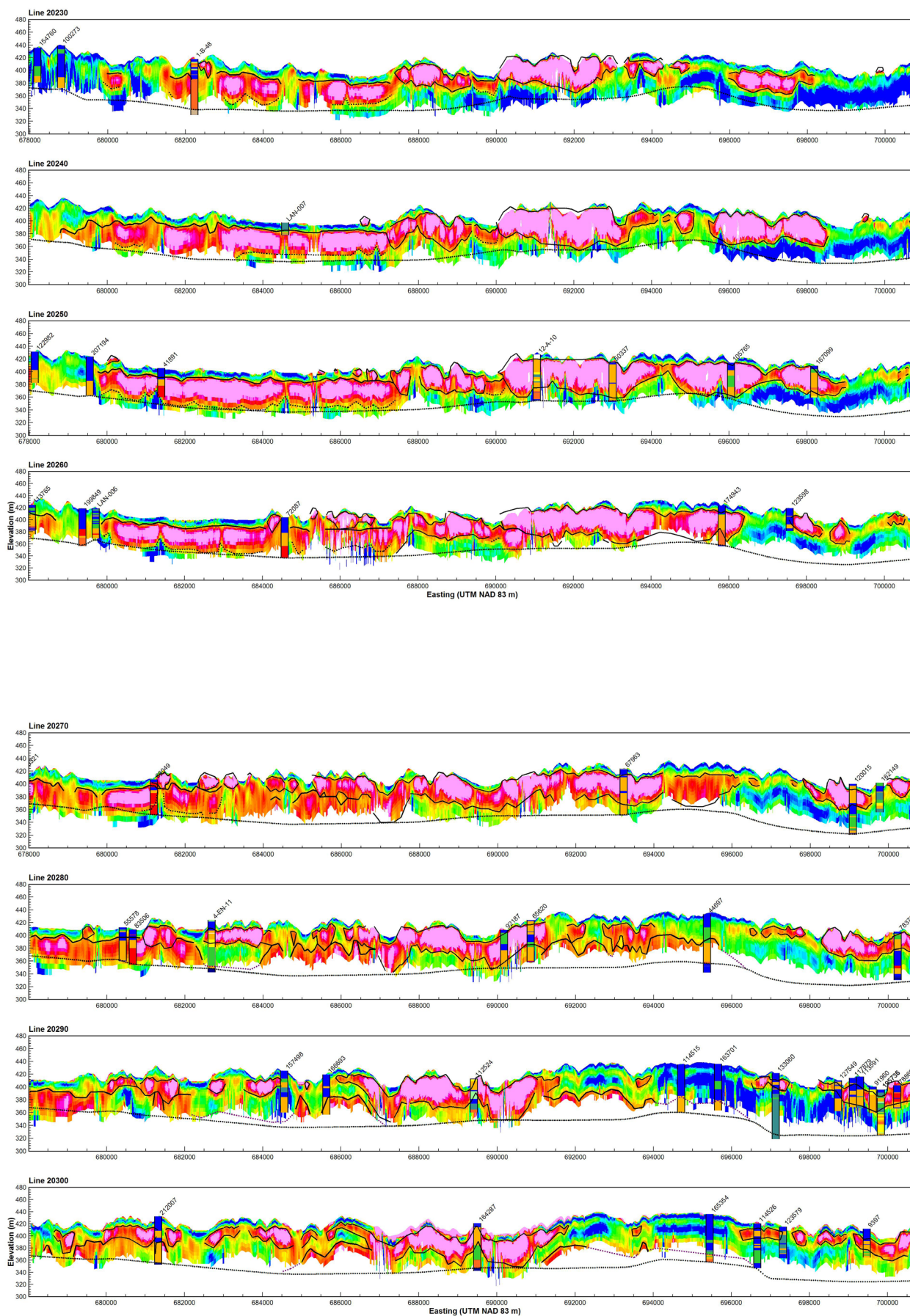




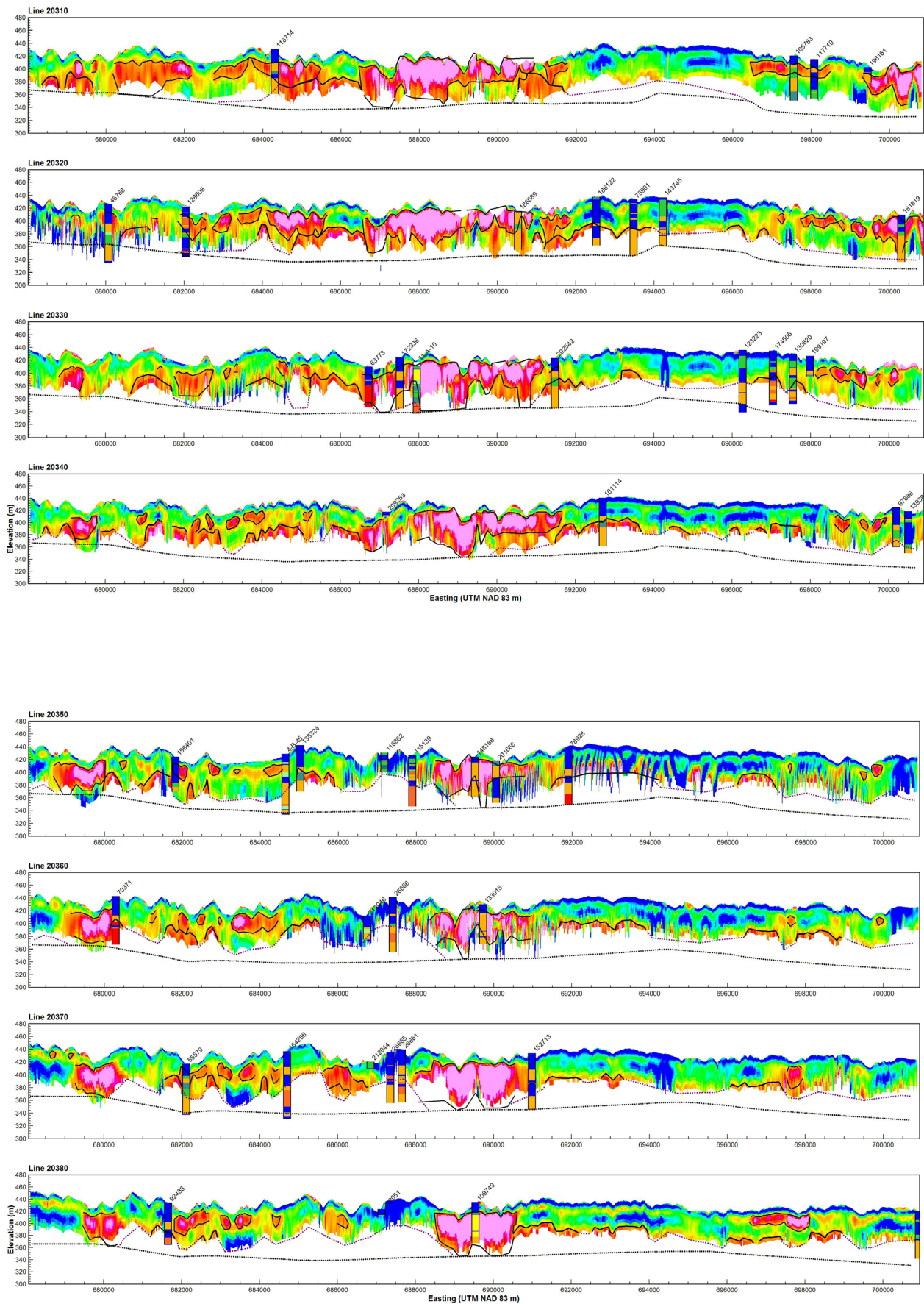
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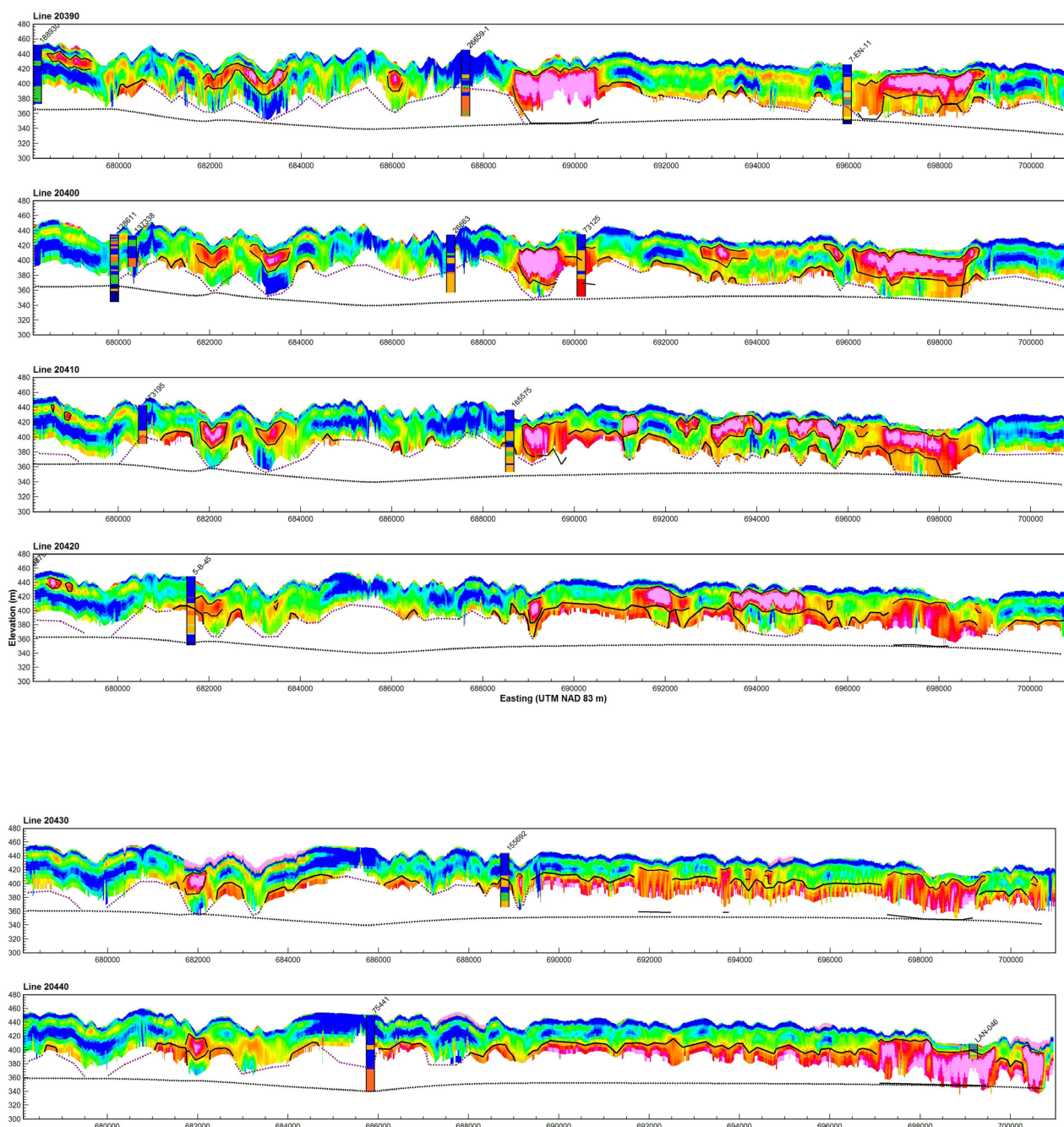




## APPENDIX A (continued)



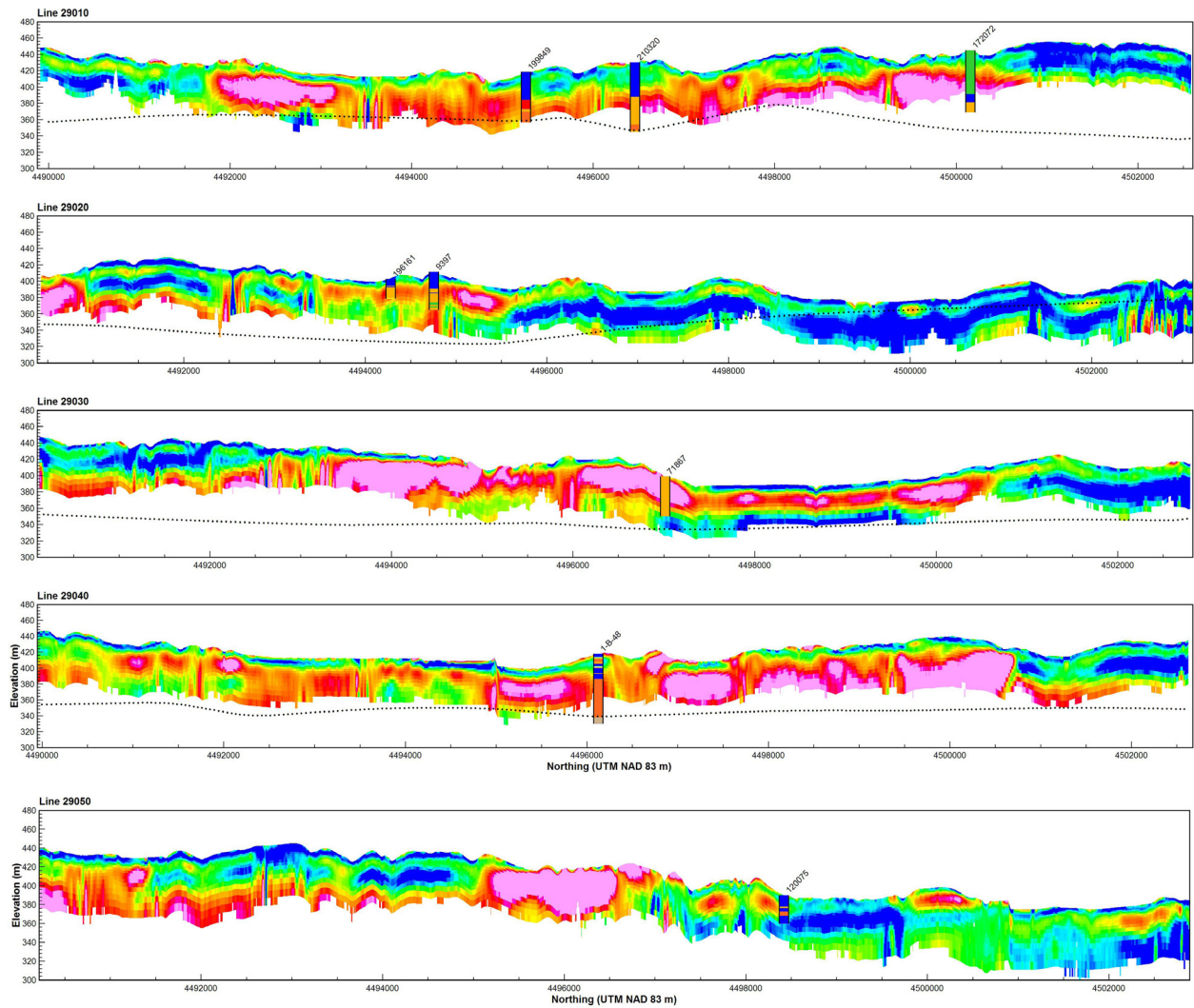




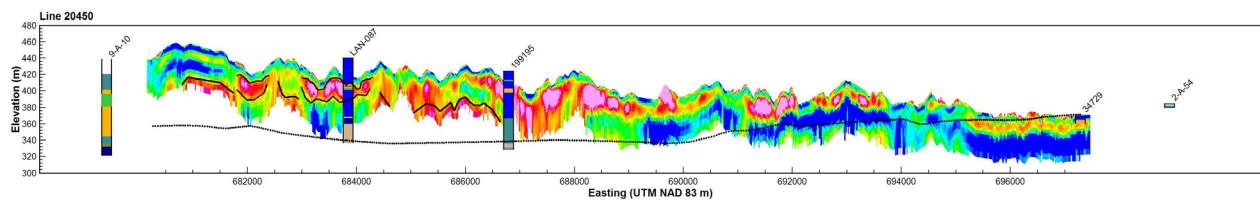


# APPENDIX A (continued)

## South to North Profiles



## Southwest to Northeast Profile





Funding for this project was provided by the Nebraska Environmental Trust and the Lower Platte South Natural Resources District.



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